PATHOGENESIS OF TRAUMATIC SHOCK AND CRUSHING DISEASE

Professor S. A. Seleznev

Translation of: "Patogenez travmaticheskogo shoka i bolezni razmozzheniya," Patologicheskaya Fiziologiya Ekstremal'nykh Sostoyaniy (Pathological Physiology of Extreme Conditions), edited by P. D. Gorizontov and N. N. Sirotinin, Moscow, "Meditsina" Press, 1973, pp. 71-106

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 MAY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,316	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PATHOGENESIS OF TRAUMATIC SHOCK AND CRUSHING DISEASE		5. Report Date MAY 1974
		6. Performing Organization Code
7. Author(s) Professor S. A. Seleznev		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Techtran Corporation P.O. Box 729 Glen Burnie, Maryland 21061		11. Contract or Grant No. NASw-2485
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of: "Patogenez travmaticheskogo shoka i bolezni razmozzheniya," Patologicheskaya Fiziologiya Ekstremal'nykh Sostoyaniy (Pathological Physiology of Extreme Conditions), edited by P. D. Gorizontov and N. N. Sirotinin, Moscow, "Meditsina" Press, 1973, pp. 71-106

16. Abstract

An historical survey is presented of the pathogenesis of shock, in the course of which the various pathological aspects of the latter are examined in detail. The pathological features of crushing and therapy for the consequences of crushing are considered within the framework of the discussion of shock.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	55	6.00

NASA-HQ

PATHOGENESIS OF TRAUMATIC SHOCK AND CRUSHING DISEASE

Professor S. A. Seleznev

During its entire history, mankind has encountered mechanical injuries. /71* They have been particularly widespread during military conflicts ("traumatic epidemic"), but the frequency and severity of mechanical injuries has begun to increase in peacetime as well with the development of technology. The reaction to mechanical injury is referred to as traumatic stupor, traumatic injury, traumatic outcome and finally, traumatic shock.

The clearest description of traumatic outcome (shock), one which has become classic, is attributed to N. I. Pirogov. The rich volume of experience obtained during the Crimean War of 1853-1856, the keen observation and considerable talent of the clinicist and scientist, enabled Pirogov to describe the picture of traumatic shock in man so clearly that many authors have used this description for decades without making any significant modifications to it (I. R. Petrov, 1947; V. I. Popov, 1953; G. D. Shushkov, 1967; P. K. D'yachenko, 1968).

The term "shock", used very widely at the present time, has acquired a very important place in the literature. The author of this term has not been determined precisely, but the majority of researchers feel that this concept as it applies to the reaction to acute mechanical trauma was first used in the English translation of a book by the consultant to the Army of Ludwig XV, Le Dran (1737), made by Latta.

The term "traumatic shock" has become nearly universal, although the concept "shock" is frequently employed still more widely and is used to represent a number of pathological processes that arise under the influence of various extreme stimuli on the organism.

More than 100 years have elapsed since the first detailed description of traumatic shock, but thus far this important problem has not left the pages of

*Numbers in the margin indicate pagination in the foreign text.

the medical press and remains a problem of great scientific importance. Interest in the study of traumatic shock increased sharply during the first World War. During those years, outstanding theoreticians and researchers of those days, men like Cannon and Bayliss became involved in the study of shock along with the clinicians. During World War II, special research groups were formed in many countries to direct scientific efforts in the field of shock. In the Soviet Union, Group no. 1, headed by M. N. Akhutin, was the most famous. /72

As far back as World War I, and particularly during World War II, it was noticed that when victims stay in the trenches for a long time and then are removed from them, a rather distinctive reaction occurs which was first described in detail by Bywaters under the name of the crush syndrome. This pathological process is usually referred to in the Soviet Union as the prolonged crushing syndrome (M. I. Kuzin, 1959). Thinking of this syndrome as a complex of symptoms, i.e., the external manifestations of a given disease which merely reflect its internal composition, its pathogenesis, we consider it more correct to refer to it as crushing disease.

The initial stages of crushing disease are essentially the same as traumatic shock, and there is no clear boundary that can be drawn between them. Many authors usually characterize the initial stages of crushing disease as traumatic shock. However, at later stages of development this disease takes on particular characteristics that are peculiar to it alone.

The mechanism of the reaction of the organism to serious mechanical injury is extremely complex, and involves all of the functional systems of the organism, while the special significance of the various pathogenetic factors during various periods of development of processes are far from identical. This is precisely why primary significance in the origin of reactions to mechanical injuries at various stages of development of science has been ascribed to various pathogenetic factors which were viewed by various authors as the primary ones. Various theories of the pathogenesis of traumatic shock have come and gone (blood, plasma loss, toxemic, acapnic, etc.) which have been described extensively in the literature (I. R. Petrov, 1947; G. D. Shushkov, 1967; I. K. Akhunbayev, G. L. Frenkel, 1967), so that there is no need to describe them once more.

In all probability, the reaction of the organism to serious mechanical injuries cannot be adequately characterized by any of the monogenetic theories. Evidently Z. A. Asratyan (1945) and V. I. Davydovskiy (1945) were correct when they said that traumatic shock may be evaluated only from the standpoint of synthetic theory, taking into account in its development the pathogenetic role of the various mechanisms.

The pathogenesis of the reactions of the organism to mechanical injuries can be determined on the one hand by the characteristics of the etiological factors and on the other by individual characteristics of the organism — its reactivity. The etiological factors are made up of the influence of the harmful mechanical stimulus — the causes and conditions under which injury occurs and which can make the seriousness of the basic pathological processes greater. This also applies to temperature factors (high and low temperature) and to radiation and biological factors as well (I. R. Petrov, 1962).

There is insufficient basis for replacing the etiological factors of traumatic shock and crushing disease with pathogenetic ones (blood loss, plasma loss, adrenal exhaustion and so forth) as is being done now.

V. I. Popov (1953), analyzing the results of the work of surgeons during World War II, stressed the fact that the etiological and pathogenetic factors /73 of traumatic shock must include the nature of the trauma, the area of the trauma and the reactivity of the organism.

In evaluating the basic etiological factor in traumatic shock and crushing disease, the harmful effect of the mechanical agent, it is necessary to take into account its intensity, which is determined by the mass of the agent doing the harm and the velocity of the effect, i.e., the momentum of the force. In addition, it is necessary to keep in mind the duration of the harmful effects, and the location and extent of the injury. During peacetime, significant injuries occur in particular during transportation traumas (railway and highway accidents), involving failure to observe safety precautions and accidents at enterprises working in the field of heavy industry as well as in mining. During wartime, both the nature and the characteristics of the effects of the harmful factors are so diverse that it is difficult at the present time to determine which of them or what combination of them can cause the most serious injuries.

Mechanical injuries lead to the development of a rather complicated set of phenomena which we have referred to in the past as "traumatic disease". This term is not generally used, although it is completely acceptable and is used by us repeatedly (S. A. Seleznev, 1964, 1967, 1968). The concept of traumatic disease is quite extensive, inasmuch as it involves a number of phenomen — all of the diverse changes in the vital activity of an organism which take place /74 during serious injuries, beginning with the moment of the injury and lasting till the outcome of the disease.

Understanding traumatic disease to consist of a entire complex of changes that arise in the organism during serious mechanical injuries (wounds, fractures, hemorrhages and so forth), traumatic shock must be viewed as one of its possible components — as one of the complex pathological processes composing it. Crushing disease can also be viewed as one of the manifestations of traumatic disease, attributing to it all of the phenomena which arise during prolonged and extensive compression of soft tissues, following decompression and in the course of reparation.

The interrelationships between the various pathological processes observed in serious injuries may be illustrated by the diagram shown in Figure 10. This diagram with all of its complexity shows the similarities and the differences in the basic mechanisms of the pathological processes that are caused by mechanical injury, to which we shall return later on.

Traumatic Shock

Traumatic shock constitutes a stereotypical reaction to a certain degree. It can be thought of as a phasal pathological process which arises during serious injuries to the organism, constituting a distinctive combination of disturbances of circulation, disruptions of the oxygen regime and related changes in metabolism that occur as the result of disintegration of nervous and humoral regulation.

The reaction of the organism to serious mechanical injuries has much in common with reactions that arise under the influence of other extreme stimuli. There is a great deal that is common to these reactions. What is thought of under the term "shock", in a wider application, is not a monopoly of traumatic

disease but can also be found in other diseases — burns, electrotrauma, etc. At each of the latter, shock acquires a specific coloration, determined by the common features of the development of the corresponding disease. Some researchers distinguish between a great many forms of shock with different etiologies (I. K. Anukhbayev, G. L. Frenkel, 1967; Hardaway, Johnson, 1963).

Traumatic shock (individual moments of its pathogenesis) may be compared with other forms of shock, but they must not be confused; otherwise it is easy to experience doubt regarding the concreteness of the concept "traumatic shock" as happened in the case of a number of researchers (M. N. Akhutin, A. N. Berkutov).

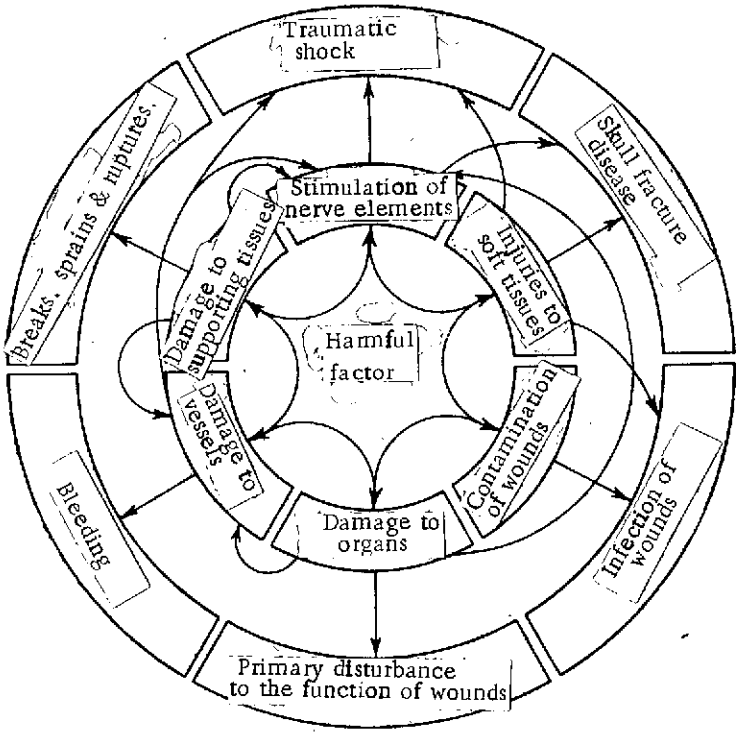

Figure 10. Diagram of the Relationships Between the Basic Pathological Processes Arising in Mechanical Trauma.

In the course of further discussion, for the purpose of analyzing the pathogenesis of traumatic shock, we will continuously refer to data touching on other types of shock. Such comparisons can often be very valuable. In an experimental study of shock, use has been made thus far of various methods of producing it: intensive mechanical traumatization of soft tissues, compression

of soft tissues by clamps, irritation of major nerve trunks by electrical shock, partial bleeding with subsequent return of the blood to the vascular bed and so forth. In these cases, processes frequently arise which are similar to traumatic shock only with respect to certain pathogenetic branches and only at certain stages at that.

The experimental study of traumatic shock, which originated at the end of the last century in the work of Krile, has undergone particularly extensive development during the last 3 decades and has contributed a great deal to the understanding of the mechanisms of this process. The experimental work of recent years and the introduction of modern recording devices to the clinic has made it possible to compare experimental shock with shock in man and to confirm once more the view that there is no theoretical difference between shock in man and shock in animals (Fine, 1967).

As we have already pointed out, even now, in examining traumatic shock, the majority of authors hold different theories of its pathogenesis, many of which are of only historical interest, but regardless of what theory of pathogenesis of shock is held by a modern researcher, he cannot disregard the significance of the combination of a number of factors in its development. Attention should be focused on the fact that as far as the pathogenesis of the latter stages of shock is concerned, the differences in appearance are not so important as in its early stages and especially its triggering mechanisms.

Characteristics of basic components of the pathogenesis of shock. The majority of Soviet researchers assign primary significance in the development of shock, particularly in its early stages, to the phasal processes in the central nervous system (initial stimulation and subsequent inhibition), arising as a result of the intensive afferent impulsation from the site of the injury. It is impossible to agree with this in theory; disturbances to the reflex regulation of functions in the early stages of development of shock, as triggering mechanisms of the latter, have acquired considerable significance. It is impossible simply to generalize about the changes in the functions of the nervous system with disturbances of the function of other systems in time, as is being done now, when speaking about the primacy of injury to the nervous system and the secondary nature of the other disturbances in traumatic shock (I. R. Petrov, 1962).

The development of phasal processes in the nervous system is determined not only by the intensive afferent impulsation from the site of the injury but also the afferent impulsation from the organs in conjunction with disruption of their functions and also the changes in lability of the nerve elements due to changes in circulation, disruptions of oxygen regime and the action of the physiologically active substances (hormones, mediators and so forth) that occur in the blood in excessive amounts.

The evaluation of the activity of the organism in the light of an examination of the functional systems, which has acquired increasing popularity in recent years (P. K. Anokhin), i.e., an evaluation in which the objects of the regulation are not combined with the mechanisms of regulation either in essence or in time, can be very valuable and may be used for discussing the pathogenesis of shock. In this regard, there are still a few important difficulties but, if we evaluate the development of shock, we will compare the changes in the activity of the various organism systems and analyze their interaction.

Emphasizing the complexity of the pathogenesis of traumatic shock, Moon (1942) gives the following formula: X + Y + Z, where X is the neurogenic component, Y is the blood loss factor and Z is toxemia. All of these factors are of considerable significance in the pathogenesis of shock, but boiling down its development to a combination of the above without taking into account the dynamics of the process, their individual roles at various stages of its development, even in a simplified form, is hardly correct.

Z. A. Asratyan (1945) and other researchers (Laborit, 1952; Hershey, 1960), evaluating the role of various pathogenetic moments in the origin of traumatic shock, point out the differences in the time of their inclusion in the total mechanism of the development of the process and their far from equal significance /76
at various periods of shock. Hence, it is quite clear that a consideration of traumatic shock is unthinkable without taking into account its dynamics—its phasal development.

The concept of the two phases in the development of traumatic shock: a primary one which arises following the trauma and takes the form of an activation of functions, called erectile, and the second one which is manifested by inhibition of functions, torpidity, was established in the work of N. N. Burdenko (1951).

The erectile phase of shock, the phase of excitation, is the initial phase of the reaction to serious mechanical injury. Externally it takes the form of motor restlessness, a cry, paleness of the coverings and mucous membranes, an increase in arterial and venous pressure, and tachycardia; sometimes there is urination and defecation. In this phase, as a result of generalized excitation and stimulation of the endocrine apparatus, the metabolic processes are activated, although their circulatory supply is inadequate. In this phase, attempts are made to produce inhibition in the nervous system with disturbances of the circulation, and an oxygen deficit develops. The erectile phase is short and usually lasts several minutes.

The torpid phase of shock is a phase of inhibition which develops following the erectile phase and involves development of hypodynamia, hyporeflexia, significant circulatory problems, particularly arterial hypotension and tachycardia, disturbances to external respiration (tachypnea initially, bradypnea or periodic respiration at the end, oliguria, hypothermia and so forth). In the torpid phase of shock, the disturbances to metabolism become more serious, due to disturbances of its neuro-humoral regulation and circulatory supply. These problems differ in various organs. The torpid phase is the most typical and longest phase of shock and its duration may be from several minutes to several hours.

In addition to the erectile and torpid phases, in serious shock, terminating in death, it is useful to distinguish the terminal phase of traumatic shock, thereby emphasizing its specificity and the difference from the prelethal stages of other pathological processes which are usually lumped together under the term "terminal states". The terminal phase is characterized by a certain type of dynamics; it begins to be indicated by problems with external respiration (Biot's or Kussmaul's respiration), instability and a sharp drop in arterial pressure, and slowing of the pulse. In the terminal phase, shock is characterized by comparatively slow development and consequently greater exhaustion of the mechanisms of adaptation, more significant than (for example) in hemorrhaging, intoxication and more serious disturbances to the functions of the organs. The restoration of functions in the treatment of shock in the terminal phase takes place with considerably more difficulty than during therapy of the terminal state, caused by blood loss, acute asphyxia and certain other effects.

The torpid phase of traumatic shock is also distinguished by a regular type of dynamics. Several authors, considering the development of the torpid phase, have broken down shock into primary and secondary varieties (Cannon, 1923; N. N. Burdenko, 1951; E. A. Asratyan, 1945). Asratyan also designated a transitional period between the primary and secondary forms of shock. However, it is obviously more correct to view traumatic shock as a single process from beginning to end, without breaking it down into primary and secondary.

I. R. Petrov (1962) divided the torpid phase into a stage of inhibition and a stage of exhaustion. I. K. Akhunbayev and G. L. Frenkel (1967), evaluating /77 the development of traumatic shock, distinguished the compensated and decompensated erectile and torpid phases. The concepts of compensation and decompensation are not very suitable for characterizing the nature of the periods of the process; it would be more correct to speak of compensation or decompensation of certain functions of the organism in shock during certain periods of the latter and to evaluate their severity as a function of the latter.

We have suggested that the torpid phase of traumatic shock be divided into an initial period, a period of stabilization and a final period. Recognizing the conditional nature of this terminology, we wish to emphasize that in the typical course of shock, in those cases when its dynamics are clearly and obviously evident, i.e., in shock which is not very severe, the torpid phase may be divided into a period of temporary adaptation of the organism to the new conditions of existence, which arise as the result of trauma (Figure 11).

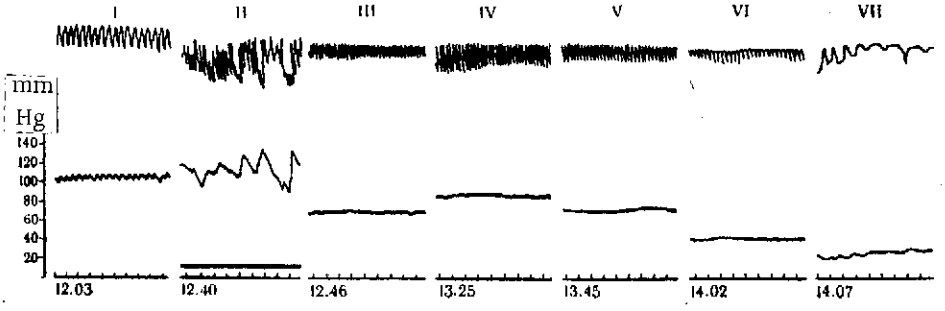

Figure 11. Changes in Arterial Pressure and Respiration During Typical Traumatic Shock in the Cat. I, Prior to shock; II, erectile phase; III, initial periods; IV-V, period of stabilization; VI, final period of torpid phase; VII, terminal phase. Top to bottom: respiration, arterial pressure, time mark (3 seconds).

In addition to the dynamics of shock, its severity must also be taken into account. This is usually characterized on the basis of the degree of disturbance to functions in the torpid phase which is most typical of shock. In our country, a 3-stage classification of traumatic shock in terms of severity has been adopted and propagated (V. I. Popov, 1953; M. G. Shraybev, 1962; I. R. Petrov, 1962). According to this classification, the concept of shock is divided as follows: mild (first degree), average (second degree) and serious (third degree). Mild shock is characterized by a slight disruption of function in the torpid phase, particularly a slight inhibition of the victim, not very significant circulatory problems with a reduction of arterial pressure to 100/60 mm Hg; recovery without using therapeutic procedures is possible. Shock of moderate severity is accompanied by significant disturbances; there is a clearly pronounced inhibition, noticeable disturbances in circulation (a drop in arterial pressure to 85/60-80/60 mm Hg), tachycardia, and hypothermia. In shock of moderate severity, in the torpid phase, one can clearly see a period of temporary adaptation. Serious shock is characterized by the rapid development of disturbances to function without apparent stabilization of the latter; the disturbances progress without interruption, and shock changes to the terminal phase if its treatment has not been undertaken.

The severity of shock is determined as the intensity of the damage as well as the reactive capacities of the organism itself. In terms of its applications to clinical practice, the concept of the severity of shock is conditional to a /78
certain extent and is governed largely by the success of therapy of this process. Simeone (1961), compared the parameters characterizing the severity of shock; according to the data from the first World War and the Korean War, he established that the same degree of severity during World War I could be applied to shock with much worse indications than in the Korean War.

Considering traumatic shock as a typical, biologically common reaction to serious trauma, it is necessary to distinguish within it, as in any other pathological process, the elements of injury and the elements of the measures of physiological protection: adaptive and compensatory phenomena. The characterization of these phenomena is very difficult and in many cases can only be done on a conditional basis.

Traumatic shock, constituting a reaction of the impact organism, is accompanied by a combined change in the activity of its functional systems, but the integrating role is played by the nervous and endocrine systems. The development of shock, particularly in its early stages, is associated with disturbances of the nervous and hormonal regulation, subsequently combined with changes in local regulation, intoxication, damage to the cellular elements of the organs and so forth.

When the organism is subjected to the action of a damaging mechanical agent, various nerve elements in the zone of injury are subjected to damage and irritation, so that not only the receptors, on which a great deal has been written (I. R. Petrov, 1962; I. K. Akhunbayev, G. L. Frenkel, 1967) but other elements as well — nerve fibers, passing through the tissues that go to make up the nerve trunks. At the same time, the receptors have a familiar specificity with respect to the stimulus, characterized by differences in the threshold value for various stimuli, nerve fibers do not differ from one another as sharply with respect to mechanical stimulation, so that the mechanical stimulation causes excitation in the carriers of a different type of sensitivity and not only pain or tactile sensations. This explains why injuries that are accompanied by breaking and tearing of large nerve trunks are characterized by severe traumatic shock.

The effect of mechanical injury cannot be limited to isolated stimulation of nerve elements: there is unavoidable injury to the vessels and tissue elements. The pathogenetic value of these factors must be taken into account in studying the mechanism of traumatic shock. Typical traumatic shock develops in those injuries in which the primary role is played by intensive afferent impulsation, i.e., in those cases when extensive receptive fields or a large number of nerve fibers are subjected to stimulation: in compound fractures, loss of extremities and so forth.

The irritation that is produced under the influence of a harmful chemical agent spreads to various levels of the nervous system. The nature of this spread is governed by a number of factors: the strength of the stimulus, the region of injury and its extent, the intensity of the afferent impulsation from

the organs with disturbed functions, the interrelationships between the irritated neurons and their lability. Stimulation of nerve elements in the zone of the trauma does not cease even after the action of the harmful agent. It is maintained by their trauma, pressure on the nerve fibers, the action of toxic products of tissue breakdown and destructive metabolism upon the receptors. The study of the biocurrents of the afferent nerve fibers in experimental shock has shown that the impulsation from the site of the injury is felt for hours (N. V. Golikov). Such a long period of the impulsation in exsured by retention of the excitability of the nerve fibers even in a deep torpid phase (G. D. Golovachev, 1960). The pathogenetic significance of the afferent impulsation is supported by the research of a number of authors who have found that in spinal anesthesia serious traumatic shock does not develop even with intensive trauma. /79

The erectile phase of shock is characterized by a generalization of excitation, which finds its external expression in motor restlessness, speech stimulation (in man), cries (in animals), increased sensitivity to various stimuli. Excitation involves the vegetative nerve centers as well, manifested by an increase in the functional activity of the endocrine apparatus and the injection of catecholamines into the blood, together with adaptive and other hormones, stimulation of the activity of the heart and an increase in the tone of the vessels of resistance, activation of metabolic processes.

Prolonged and intensive impulsation from the site of the injury, and subsequently from organs with disturbed functions, changes in the lability of the nerve elements in conjunction with disturbances of circulation and the oxygen regime govern the subsequent development of the inhibition process. The irradiation of the irritant — its generalization — is a necessary prerequisite for the development of inhibition (A. A. Ukhtomskiy). Inhibition develops first of all in those parts of the nervous system which have the least lability and to which the flow of impulses is most intensive.

The question of the initial localization of the foci of inhibition in the central nervous system in traumatic shock, their stability and tendency toward spreading is extremely important but complicated and still insufficiently studied. In the course of the formation of concepts regarding shock, it has been

viewed from various standpoints. The most likely one is the viewpoint of the mosiac nature and mobility of foci of inhibition in the torpid phase of shock, (I. V. Davydovskiy, 1954; V. K. Kulagin, 1965; S. A. Seleznev, 1964). Inhibition, being an active process by nature, ensures the possibility of the restoration of the energy resources in the nerve cells, which is extremely important for their further functioning.

The data on the early development of inhibition in those segments of the spinal cord where the neurons are located which innervate the zone of the injury is very convincing, although inhibition in these segments is not characterized by considerable depth or stability.

V. M. Vinogradov et al. (1960), and P. K. D'yachenko (1968) established that in experimental shock, caused by stimulation of the sciatic nerve, the inhibitory process develops early in the zone of the reticular formation of the brain stem. Inhibition in the zone of the reticular formation, in the opinion of these authors, protects the cerebral cortex against the influx of impulses from the periphery, ensuring retention of its functions.

Peterson and Haugen (1963), in experiments involving the production of hemorrhagic shock, showed that the elements of the reticular formation which facilitate the conduction of impulses (RF^+) are more sensitive to disturbances of circulation than are the ones which inhibit the conduction of impulses (RF^-). From this it follows that the circulatory disturbances in this zone must promote the functional blockage of the conduct of impulses.

Attention was directed recently to the importance of the role played in the development of shock reactions by cortical inhibition and inhibition in the subcortical formations (I. R. Petrov et al.). In subsequent works of these in- /80
vestigators, particular emphasis has been placed on inhibition in the subcortex. The concept of a subcortex, as we know, is collective to a large degree: it includes the formations of various structures and a functional significance whose role is largely still unclear, so that it is still difficult to evaluate its pathogenetic significance.

According to the experimental data of V. S. Shevelva, the inhibitory process in shock first arises in the sympathetic centers and the hypothalamic

region, and only later — when the process has advanced considerably — in the cerebral cortex. These data of Sheveleva correspond to the views expressed in the 1930s in the works of N. N. Burdenko, who placed great importance upon disturbances of the functions of the sympathetic nervous system in the origin of traumatic shock.

I. I. Fedorov and D. M. Sherman (1961), expanding upon the data in the literature concerning disturbances of nervous regulation in traumatic shock, concluded that there is a possibility of the early formation of inhibition in the thalamic region, i.e., in that zone where an interchange between conductors of all types of sensitivity takes place. This inhibition, in their opinion, protects the cerebral cortex against overstimulation. They emphasize the extremely great significance of the mosaic nature of the processes in the nervous system, which may be the cause of functional dissociation between the branches of the nervous system at different levels.

In order to understand the pathogenesis of traumatic shock, it is very important to have data on the phasal processes in the bulbar branch of the brain, where the most important vegetative nerve centers are located, particularly the vasomotor and respiratory centers. As we know, a nerve center is a concept which is functional to a large degree and its boundaries cannot be restricted to a single specific region of the brain. The secondary parts of the nerve centers are located at different levels in the nervous system, and the various nerve centers function jointly in part.

Data involving the changes in the functional activity of the bulbar region in the process of the development of shock are based primarily upon the study of the vascular and respiratory reflexes. A decrease in the pressor vascular reactions in response to stimulation of the sensory nerves during shock has been observed repeatedly (P. L. Veselkin, 1938; I. R. Petrov, 1947; V. K. Kulagin, 1965). Aberration of these processes has been established (development of biphasal reactions), as well as an increase in the levels of their threshold stimulation. We know that the development of wavelike response reactions with "stimulating" influences is an indication of their incompleteness.

G. L. Zavetnaya (1968), studying the sinocarotid reflexes, simultaneously measured the pressure in the zone of the carotid sinus. She found that in

traumatic shock (in its torpid phase) the sinocarotid pressor reflexes decrease in magnitude and frequently are distorted, while the depressor reflexes are significantly inhibited. However, she did not succeed in finding any strict force relationships between the stimulation and the changes in the magnitude of the response reactions (Figure 12). It was also determined in the work of G. L. Zavetnaya that the visceral vascular reflexes which are completed on the segmentary level are more stable during shock, which is in complete agreement with the data on the lower level of inhibition in the spinal cord.

All of these data indicate that the generalized stimulation of the nervous system, characteristic of the erectile phase of traumatic shock, results in the development of inhibition which takes the form of a mosaic nature of its foci in both a spatial and temporal respect. The inhibition is propagated /81 to the different levels of the nervous system. It has a tendency to become more profound due to impulsation from the region of the trauma, which takes place even after the action of the harmful agent has ceased, and also due to an influx of impulses from organs with a disturbed function. The nature of this inhibition is not monogenetic; for some zones the development of inhibition is characteristically excessive, while for others it follows the induction type.

The phase phenomena in the nervous system are manifested by disturbances of regulation and disruption of activity, affecting practically all functional systems of the organism. On the other hand, disturbances of the activity of the organism systems, particularly disturbances of circulation, respiration, excretion and so forth are expressed through the functional status of the nervous elements.

Changes in the regulation of the activity of various systems and organs, characteristic of traumatic shock, are caused by disturbances not only in the reflex but also the humoral regulation, especially hormonal. Among the endocrine glands, the transmission of the reaction of the organism to trauma involves to a large extent those which are distinguished by rapid response and whose hormones play an important role in the adaptation of the organism. A particularly important role is played by the hypophyseal-adrenal system. The point of view regarding the important role of the reaction of the

hypophyseal-adrenal system in the genesis of traumatic shock has been particularly widespread in conjunction with the concepts of Selye on stress.

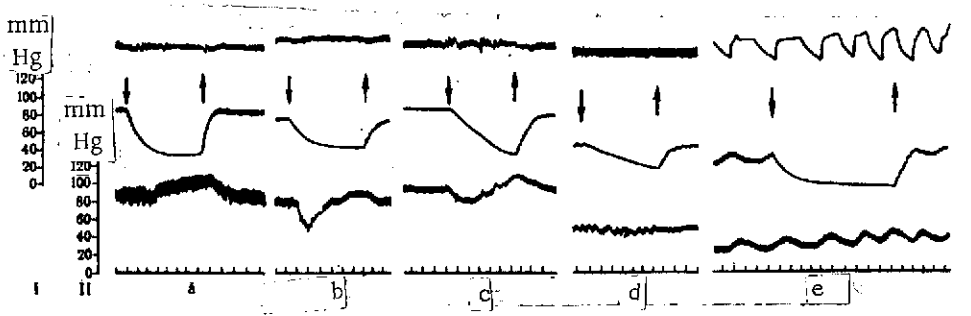

Figure 12. Sinocarotid Pressor Reflexes in Traumatic Shock (After G. L. Zavetnaya). a, Before shock; b, c, d, at various periods of torpid phase; e, in the terminal phase. Top to bottom: respiration, pressure in the carotid sinus, systemic arterial pressure, time mark (3 seconds). I, pressure scale in the carotid sinus, II, scale of systemic arterial pressure.

An analysis of the views of Selye can be found in many references in the literature (P. D. Gorizontov, T. N. Protasova, 1966) and there is hardly any need to take up this concept again in detail. It is clear that the intensive mechanical trauma is accompanied by an increase in the tone of the sympathetic nervous system, the ejection of adrenaline into the blood, stimulation of the anterior lobe of the pituitary, increased ACTH synthesis, increased secretion of adrenal hormones (gluco- and mineralocorticoids). These phenomena are in an unquestionably important (but not exclusive) position as far as the pathogenesis of the reaction of the organism to serious trauma is concerned).

The development of the functional activity of the hypophyseal-adrenal system in traumatic shock is supported by experimental (V. K. Kulagin, 1965) and clinical observations (Yu. N. Tsibin, 1960). The activation of the hypophyseal-adrenal system is indicated by the change in the content of hormones (ACTH and 17-oxycorticosteroids) in the blood, increased excretion of 17-keto- /82
steroids with the urine, changes in the content of ascorbic acid in the adrenals, and the development of eosino- and lymphopenia.

In the later stages of shock, and with a very serious process and in the early periods thereof, there is a gradual beginning of development of interrenal insufficiency (V. K. Kulagin, Yu. N. Tsibin). Analyzing the mechanism of this insufficiency, G. S. Mazurkevich showed that an increase in the concentration

of 17-oxycorticosteroids in the blood is far from adequate to the changes in the ACTH content; the increase in the ACTH content during the latter period of shock is not accompanied, as is usually the case, by the injection into the blood of 17-oxycorticosteroids. In prolonged shock, when the reaction of the cortical layers of the adrenals to endogenic ACTH is significantly reduced, marked morphological changes are seen in this layer, particularly its fascicular zone.

The reaction of the adrenals to ACTH administered externally is retained all the way to the most severe degrees of shock. Evidently the inhibition of the functions of the cortical layer is largely due to insufficiency of the pituitary.

Interesting experimental data are presented by L. T. Lysyy (1939). In traumatic shock resulting from compression of soft tissues, he found phasal changes in the content of corticosteroids in the blood: an increase in the erectile phase and a decrease in the developed torpid phase. In the erectile phase of shock, there was a significant increase in the content of hormone that was not bound with plasma proteins. However, the amount of unbound hormone in the torpid phase decreased, though it exceeded the usual level significantly. According to the data of L. T. Lysyy, the content of hormones in various tissues in shock is not the same; thus, the tissues of the brain and heart have levels which are higher than those in the liver tissue. Under shock conditions, there is a certain degree of parallelism which develops between the content of the hormones in the tissues and the activity of the respiratory enzymes.

A very typical feature of traumatic shock is hyperadrenalinemia. It was described in the work of Cannon (1923) and N. N. Burdenko (1951). The pathogenetic significance of hyperadrenalinemia was studied and evaluated in later works. The increase in blood adrenaline content has been linked by some authors with an increase in the tone of the resistant vessels (small arteries, arterioles, metarterioles of the precapillary sphincters) and hyperglycemia, which occurs even in the erectile phase of shock. Hyperadrenalinemia, on the one hand, is a consequence of intensive afferent impulsation, caused by injury, and on the other hand is a reaction to the gradual development of arterial hypotonia. There are data in the literature which indicate that a decrease in arterial

pressure in the vicinity of the carotid sinus is accompanied by an increase in the concentration of catecholamines in the blood.

Unfortunately, it is not possible to evaluate all of the problems in the humoral regulation of functions in traumatic shock due to their profusion. Zweifach (1961), studying the humoral factors of shock, isolated them into 4 groups: tissue metabolites (products of the anaerobic metabolism, adenylic bodies, ferritin, and so forth), derivates of blood (histamine, 5-oxytryptamine, kinins), factors of the insufficiency of neuro-humoral regulation and bacterial exo- and endotoxins. The first 3 groups of factors have the most direct relationships to traumatic shock.

V. A. Levtov (1967), considering the endogenic vasoactive substances, proposes dividing them into 3 groups: the nonspecific metabolites (carbon dioxide, organic acids, ions, adenosine nucleotides), local hormones (histamine, serotinin, acetylcholine, bradykinin) and the vasoactive hormones, carried by the blood (vasopressin, catecholamines, renin-angiotensins).

In discussing humoral factors as they apply to the pathogenesis of traumatic shock, the greatest amount of attention has been paid to their vasoactive properties, although many of them may have an influence on the state of tissue and vascular membranes and on the metabolic processes (kinins, histamine, and so forth). It seems to us that two trends must be taken into account in the classification of humoral factors: the level at which they act (locally or on the level of the organism as a whole), and whether these substances are ordinary physiological regulators, or whether they occur only under pathological conditions. Nonspecific metabolites and local hormones are of great importance in the regulation of tissue blood flow and under ordinary conditions but during shock, when it is possible to have an excess accumulation of them, their action may exceed the local limits. In the course of development of shock, the vasoactive and toxic substances may be resorbed from the zone of the injury, but according to the data of certain authors, they may be asborbed from the intestine as well in accordance with changes in the intestinal blood flow, the properties of the intestinal wall and the antitoxic function of the liver. /83

At one time histamine was attributed very great significance in the pathogenesis of traumatic shock. This substance as we know can be liberated from

the tissues in various injuries. The theoretical possibility of the resorption of histamine from the focus of injury in mechanical trauma, accompanied by shock, has been quite definitely established at the present time.

At the present time, very little is known about the role of serotonin (5-OTA) which causes vasoconstrictory and sometimes vasodilatory reactions in the mechanism of traumatic shock. The determination of the nature of its activity in several forms of shock has not yet led to any kind of definite results. At the same time, however, we know that hypoxia of muscle is accompanied by liberation of serotonin (V. A. Levtov, 1967).

Bradykinin is one of the most active hypotensive polypeptides which are of unquestioned significance in the local regulation of blood circulation in normal and especially pathological conditions, possessing a pronounced depressor effect. Judging from the data of certain authors, it causes an increase in the tone of the arteriovenous anastomoses and a contraction of the small veins. There are data which indicate that bradykinin plays an important role in the development of arterial hypotension in trauma.

Adenylic substances, which as we know, have a vasodilatory effect, are accumulated in excessive amounts under hypoxic conditions. However, hypoxia is typical of shock, as we shall see later on. The pathogenetic significance of adenylic substances in traumatic shock was mentioned by E. A. Asratyan (1945) and later by Zweifach (1961).

An important role in the development of the hypotensive reaction which arises in shock was awarded by Zweifach to VDW (vasodepressor material) or ferritin. The mechanism of action of ferritin, whose deactivation in the liver during hypoxia of the latter is disrupted, on the vessels is still not completely clear, but there is reason to believe that it has adrenolytic properties. After Zweifach, several other authors (I. R. Petrov, 1962; G. D. Shushkov, 1967) mentioned ferritin as one of the factors that governed arterial hypotension under shock conditions.

Without dwelling further on the changes in the humoral regulation during shock and its significance in the pathogenesis of this process, we will note that it is particularly important to the status of the activity of the

cardiovascular system. A number of researchers, including Yu. N. Tsibin in our laboratory, using the method of perfusion of isolated organs, established that there was a gradual increase in vasoactive substances in the blood with the development of the traumatic form of shock. Yu. N. Tsibin, who studied the /84
same blood samples with respect to vessels from various organs, concluded that their reaction was not the same. He suggested that these differences in the reaction of the vessels could be of significance in the mechanism of disruption of circulation of the blood.

Changes in reflex and humoral regulation govern the diverse changes in the activities of the systems of the organism which are characteristic of traumatic shock; on the other hand, as we have already emphasized, the changes in the activity of these systems have a not insignificant effect upon the condition of reflex and humoral regulation. Some investigators, studying interactions of this type, have employed the concept of vicious circles -- a concept which has existed in medicine since the very earliest times. It seems to us that isolation of a limited category of phenomena constituting the vicious circle from the very many phenomena which are linked in a wide variety of relationships, significantly limits the possibility of viewing the pathological process in all of its aspects. At the same time, however, it is impossible to proceed without /85
analyzing the direct and feedback influences of disturbances in the activity of the various organic systems and comparing them with adaptive reactions. One may convince oneself of this fact by examining the very general scheme of shock pathogenesis which demonstrates the most important pathogenetic factors and their interrelationships (Figure 13).

First of all the changes in reflex and humoral regulation are expressed in the activity of the circulatory apparatus. This develops practically immediately after the trauma, but the changes in the circulation affect the functional state of the regulatory system with equal speed. These types of interrelationships can be seen throughout shock.

Circulatory disturbances in traumatic shock are manifested very clearly but do not receive the most attention in studies of this process.

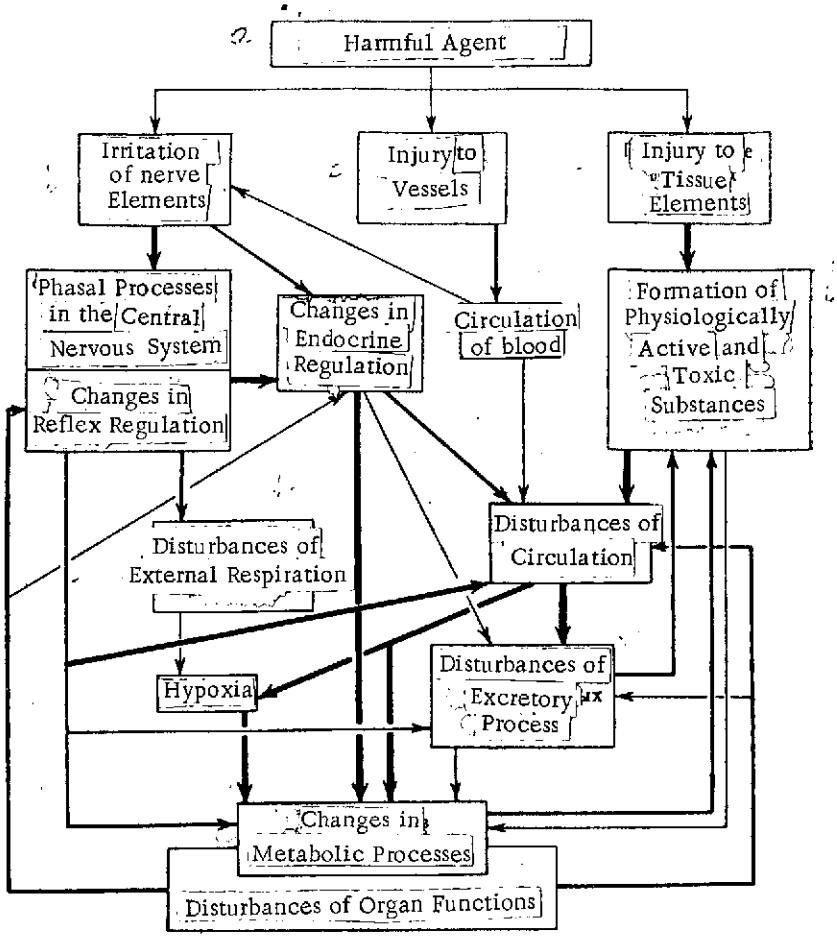

Figure 13. Diagram of the Pathogenesis of Traumatic Shock

One of the most typical symptoms of traumatic shock is the phasal changes in arterial pressure -- its increase in the erectile phase and its decrease in the torpid phase. The diagnostic value of data on arterial pressure changes is unquestionable but, if we look at this parameter in isolation, aside from its relationship to other parameters which characterize the circulation of the blood, metabolism and so on, it is impossible to evaluate such a complicated process as traumatic shock with sufficient objectiveness. The arterial pressure value is, as we know, governed by the relationships between the cardiac output and the total peripheral resistance, while the linear flow velocity from the arterial protion of the vascular bed into the venous in its turn depends upon the pressure level. At any given value of cardiac output, the blood flow in

certain organs cannot be determined unambiguously: it depends upon the interrelationships between the intraorganic vessels and the functional condition of the terminal vascular bed in a given organ at any given moment.

In recent years, increasing data have come to light which indicate that regulation of the activity of the circulatory system amounts to ensuring the productivity of the heart (minute volume of circulation), and adequate intensity of metabolism, characterized by the oxygen demand of the tissues. The accumulation of metabolites in the tissues, which have a local vasostimulant effect, determines the magnitude of local tone and systematic regulation under these conditions ensures selection of the most optimum system of blood supply. The increase in arterial pressure which is typical of the erectile phase of traumatic shock is the result of an increase in the total peripheral resistance of the vessels as a consequence of the generalized spasm of the resistive vessels, caused by activation of the sympathetic-adrenal system (S. A. Seleznev, O. P. Khrabrova, 1967). The tone of the resistive vessels is increased together with activation of arteriovenous anastomoses and ejection of blood from the high-pressure vascular system (arterial bed) into the low-pressure vessel system (venous bed), causing an increase in venous pressure and preventing escape of blood from the capillaries. If we take into account the fact that the majority of capillaries lack sphincters at their venous ends (Zweifach, 1961), it is easy to see that under these conditions it is possible to have not only direct but retrograde plethora of the capillaries.

These circulatory changes cause the onset of hypoxia, especially since in the erectile phase they are combined with stimulation of metabolism. On the other hand, retention of blood in large vessels (venules and small veins) and capillaries -- its deposits -- causes a decrease in the volume of circulating blood. The exclusion of a portion of the blood from the active circulation can /86 be clearly observed at the end of the erectile phase of shock. At the beginning of the torpid phase the hypovolemia is even more pronounced than in the subsequent periods of shock.

Hypovolemia has always been ascribed significant importance in the pathogenesis of traumatic shock. Many authors (Blalock, Wiggers et al.) considered it to be most important and even the basic factor in the pathogenesis of shock.

As shock becomes deeper and passes to the torpid phase, the total peripheral resistance of the vascular bed decreases, but this in no way indicates a uniform total decrease in the tone of all the vessels, but is simply a reflection of distinctive vascular dystonia -- the result of significant changes in the vascular tone of certain organs with small changes in others. There is reason to believe that the tone of various types of terminal vessels under the conditions of shock changes in varying degrees; thus, the tone of the arterioles and precapillaries exceeds the tone of the metarterioles and the arterial-venous anastomoses.

The decrease in the total peripheral resistance and productivity of the heart, the latter unavoidably due to the hypovolemia and the decrease in venous return, is expressed by the arterial hypotension characteristic of the torpid phase of traumatic shock (Figure 14). Under ordinary conditions (with adequate changes in cardiac output and vascular resistance) they change reciprocally. In shock, however, there is a distinctive difference in the changes between these hemodynamic parameters. The decrease in the minute volume of the blood circulation is typical of various types of shock, including traumatic shock (S. A. Seleznev, O. P. Khrabrova, 1967).

In the torpid phase of moderately-severe traumatic shock, a direct relationship can be established between the productivity of the heart, hypovolemia, and arterial hypotension (S. A. Seleznev, 1964, 1968). In the torpid phase of /87
severe shock, however, no such relationship can be seen.

Deposition of the blood in traumatic shock is observed in the vessels of the various organs (N. N. Burdenko, 1951; S. A. Seleznev, 1964). The deposition of the blood considerably aids the significant potential possibilities of the capillaries and capacious vessels in the low-pressure system (Burton, 1966).

It is important to note that in the capillaries and voluminous vessels, as was shown by experiments involving the study of the microcirculation (O. P. Khrabrova, 1970) more formed elements are contained than in the blood plasma. This phenomena can be linked to the characteristics of the microcirculation rheology during shock, specifically to the changes in redistribution between the plasma and the formed elements of the blood stream and also to the characteristics of the rheological properties of the blood -- the tendency of the formed

elements toward sedimentation and aggregation. Traumatic shock in its torpid phase is characterized by a decrease in the hematocrit value for a mixed venous blood. These data on the microcirculation characteristics make it possible to explain this phenomenon.

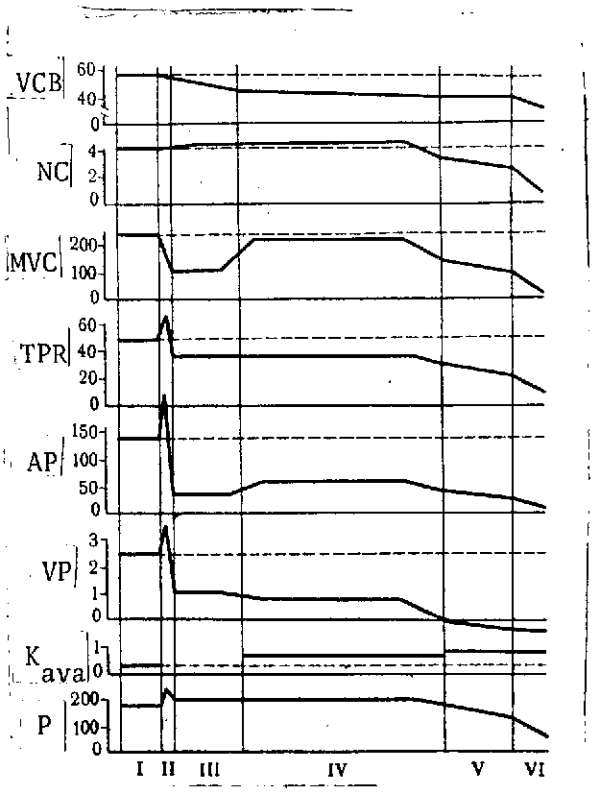

Figure 14. Changes in Basic Hemodynamic Parameters With Experimental Traumatic Shock.

VCB, Volume of circulating blood (ml/kg); NC, Number of cycles of blood (minutes); MVC, Minute volume of circulation of the blood (ml/min/kg); TPR, Total peripheral resistance (10^3 dynes·sec·cm^{-5}), relative to 1 kg animal weight; AP, Systemic arterial pressure (mm Hg); VP, Venous pressure in the posterior vena cava (mm water column); K_{ava}, Coefficient of activity of arteriovenous anastomoses; P, pulse (beats/min); I, Initial state; II, Erectile phase; III, IV, V, Beginning, period of stabilization and end of torpid phase; VI, Terminal phase.

In serious shock the disturbances in circulation gradually become more serious, taking the form of an increasing inability of cardiac output to match the magnitude of vascular tone. In shock of mild and moderate severity, it is possible for functions, including the circulatory apparatus activity, to stabilize. This stabilization may be temporary and sometimes (if the shock is severe) permanent, beginning with an increase in the productivity of the heart due to a solid increase in circulation and an increase in the number of cycles of the blood. Increasing the number of cycles of the blood to some extent promotes centralization of the circulation, i.e., that type of distribution in which certain organs are supplied with blood to a greater extent (nearly normal) than the others (Figure 15).

In full agreement with centralization of the circulation

are the changes in microcirculation which, together with general features, differ in various organs as far as the depth of disturbances is concerned. They are more pronounced in the muscles, intestines, subcutaneous cell structure and even the liver than in the pial vessels of the brain.

There are no significant differences of opinion in the literature as to the fact that the productivity of the heart during traumatic shock decreases. This cannot be said for the resistance of the vessels. Some authors working with experimental traumatic shock have found an increase in the total peripheral resistance, while they attribute the arterial hypotension completely and totally to the decrease in the cardiac output. However our studies show that traumatic shock is characterized by vascular dystonia, taking the form of an increase in the resistance to blood flow on the part of resistive vessels (small arteries, arterioles) and activation of the shunt vessels. There is reason to believe that the increase in resistance to blood flow is caused not only by active changes in tone but also by retention of the blood in the capillaries and post-capillary venules. According to the data of Burton (1966), about 47% of the total peripheral resistance involves the terminal arteries and arterioles under ordinary conditions, while 27% is in the capillaries. In traumatic shock the amount of capillary resistance, at least in certain tissues, may increase. It should be added that aggregation of formed elements can considerably increase the dynamic viscosity of the blood at low rates of change.

Hypovolemia in the torpid phase of shock, particularly its late periods, /88 is due at least to two factors -- deposition of blood, which we have already mentioned, and extravasation of its fluid portion. As shock becomes more deep, /89 the relationships between the hydrostatic and onco-osmotic forces in the capillaries and the post-capillary venules change more and more, and the properties of the vascular walls themselves change (their permeability). As a rule, when authors write about the increased permeability of vessels in traumatic shock, they have in mind not the permeability of the vascular wall as such, but the changes in the volume of fluid between the blood and tissues, i.e., extravasation of fluid. However, the percentile value of the ratio of hydrostatic and onco-osmotic forces and the state of the intrinsically permeable vascular wall still remains unclear.

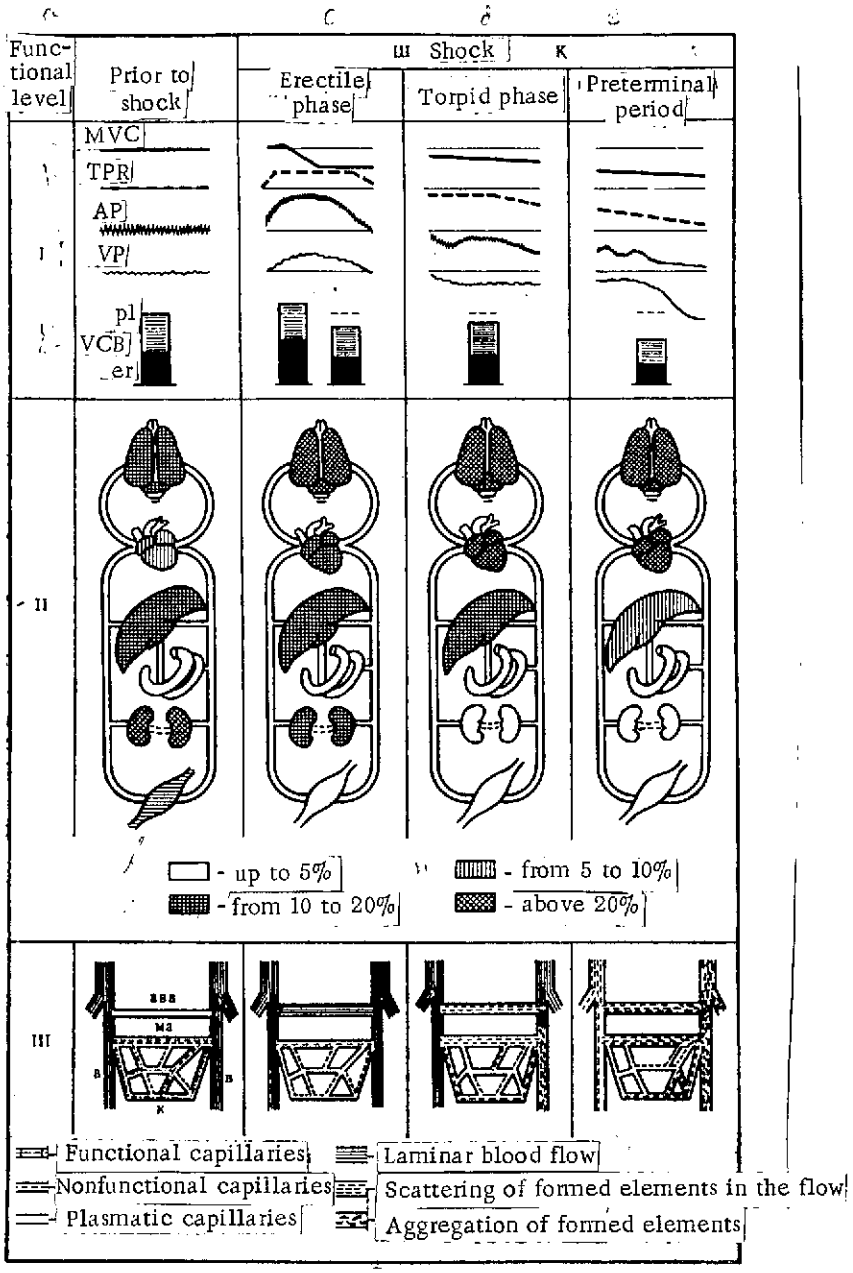

Figure 15. Nature of Circulatory Disturbances During Traumatic Shock as they Apply to Different Functional Levels

I, Systemic disturbances; MVC; pl - plasma, er - formed elements; other symbols same as in Figure 14; II, Changes in organic circulation -- organic fractions of cardiac output; III, Microcirculation; a, arteriole; v, venule; ava, arterial venous anastomoses; ma, metarteriole; c, capillaries.

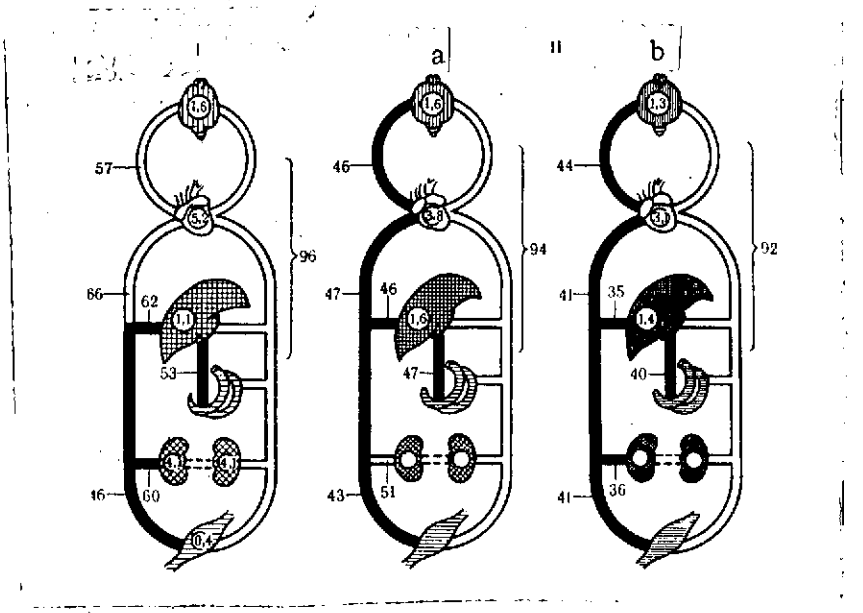

Figure 16. Indices of Oxygen Regime During Traumatic Shock
Numbers without circles: oxygenation of the blood in various parts of the vascular bed (in % of oxyhemoglobin); Numbers in circles: oxygen tension in organs (in arbitrary units). I, Before shock; II, Torpid phase of shock; a, Beginning; b, End.

The disturbances in circulation are very closely linked to the development of hypoxia -- one of the very important aspects of traumatic shock pathogenesis. Hypoxia in traumatic shock, in the opinion of the majority of investigators (Moon, 1942; G. D. Shushkov, 1967; S. A. Seleznev, 1968), is the consequence of the limitation of access of oxygen as the result of the circulatory disturbances. A definite role is played in the genesis of shock hypoxia by the hemic component which is conditioned by the decrease in the oxygen capacity of the blood due to its dilution and the aggregation of erythrocytes, as well as disturbances in external respiration, but the basic responsibility still belongs to the decrease in tissue perfusion and redistribution of blood flow between the terminal vessels.

The saturation of the arterial blood with oxygen and the oxygen tension in this blood in the torpid phase of traumatic shock not only fail to decrease but sometimes even increase somewhat (S. A. Seleznev, 1964; I. A. Il'inskiy, 1967).

A sufficiently good arterialization of the blood in the lungs is the obvious consequence of a decrease in the minute volume of circulation. As we know, one of the most important factors governing gas exchange in the lungs is the relationship between the ventilation and perfusion of the lungs with blood. The relationship between these parameters is subject to considerable variation. There is reason to believe that during the torpid phase of traumatic shock there /90 is no significant disproportion in the "ventilation-perfusion" relationship for a long period of time. However, due to the decrease in the volume of the tissue blood flow, the amount of oxygen utilized by the tissues decreases.

Oxygenation of venous blood with developing shock decreases constantly. There is a gradual increase in the arterial-venous difference with respect to oxygen, which once again reflects an increase in the utilization of oxygen per unit volume of blood due to the slowing-down of the circulation. The venous blood, flowing out from various organs, is oxygenated to a far from uniform degree (Figure 16), which reflects the differences in the oxygen regimes of the organs.

Hypoxia in the initial periods of the torpid phase is accompanied by hypocapnia, caused by hypoventilation, but later carbon dioxide can be seen to accumulate in the organism.

The changes in external respiration undoubtedly influence the oxygen balance of the organism under conditions of shock. Stimulation of the tissue and the vascular receptors, and later, changes in the excitability of the nerve elements of the respiratory center as well, produce the typical changes associated with shock in the external respiration: polypnea -- during the early periods of the torpid phase, a gradual slowing-down of respiration, and finally in the preterminal period, the onset of periodic respiration (Figure 17). The onset of periodic respiration is an indication of a change in the excitability of the respiratory center due to its hypoxia. The tissue elements under conditions of shock retain their ability to utilize oxygen for a long time. This indicates that the respiratory enzyme system is by no means damaged immediately as the shock reaction develops.

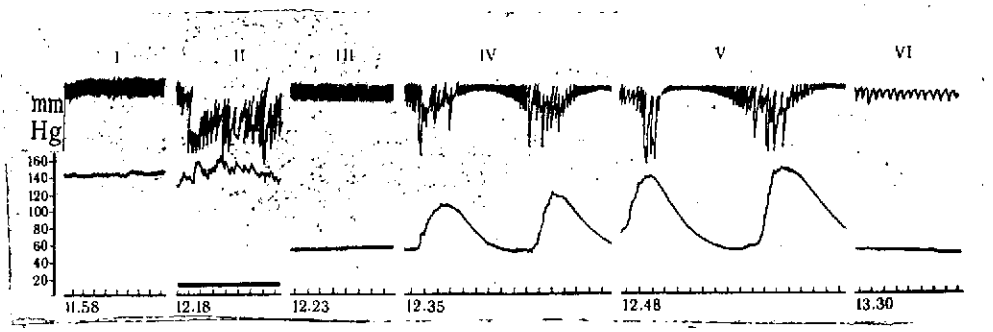

Figure 17. Periodic Respiration in Serious Traumatic Shock (Kymogram of an experiment on a cat).
I, Prior to shock; II, Erectile phase; III-VI, Torpid phase. Top to bottom: respiration, arterial pressure, time mark (3 seconds).

It is quite clear that the changes in the circulation and the oxygen regime of the organs must have some influence on the course of the metabolic processes which are also governed directly by neuro-humoral control.

As far back as 1920, Aub showed that in traumatic shock there is a significant decrease in the basal metabolism, which is most likely caused by significant changes in carbohydrate metabolism, since it is precisely this carbohydrate metabolism which is chiefly responsible for the energy consumption of the organism.

Stimulation of carbohydrate catabolism in the erectile phase of shock, combined with hypoxia, leads to a sharp decrease in the glycogen supply to the organs, and changes in the relationships between the glycolytic and oxidative phases of carbohydrate metabolism toward the dominance of the former. As a /91
result, both hyperglycemia and hyperlactacidemia develop (V. I. Popov, 1936; I. R. Petrov, 1962; S. A. Seleznev, 1964). There is an increase in the lactate/pyruvate ratio, reflecting a predominance of the glycolytic processes. At the very beginning of the torpid phase the glycogen supply to certain tissues decreases to a critical level.

The data in the literature on the level of metabolism in various organs are quite limited. Some interesting observations were made by I. R. Petrov and his associates who showed that, during the torpid phase of traumatic shock, there is a decrease in the content of creatine phosphate and ATP in the brain tissue and

a simultaneous increase in its inorganic phosphorous and lactic acid content. It was shown that, as shock develops, there is not only an increase in the level of lactic acid in the brain tissue, but also an increase in the ratio between lactate and pyruvate, disturbance of ATP resynthesis and accumulation of its dephosphorylization products. The accumulation of lactic acid in various functional portions of the brain was approximately the same.

Several investigators have established that as shock develops there is a decrease in the glycogen supply to the myocardium. However, if we take into account the characteristics of the myocardium's energetics, especially its ability to utilize lactic and pyroracemic acid, and also the fact that the myocardium energetics are determined to a large degree not by its own intrinsic supplies but by its supply from the blood, the pathogenetic significance of this fact in shock is difficult to evaluate. The ability of the myocardium to utilize the products of incomplete carbohydrate metabolism to cover its energy consumption is probably responsible for the long period of time during which it retains its functions under shock conditions. This is assisted by the rather good oxygen supply which it enjoys (in comparison with other organs) due to the relatively high cardiac fraction of the minute volume of the circulation.

The oxygen tension in the myocardium in the torpid phase of traumatic shock, as shown by the experiments of I. A. Il'inskiy, remains at a level close to normal, and it is only as the terminal phase approaches that it begins to decrease. It is no accident that many authors view disturbances in coronary circulation and myocardial hypoxia in shock as the critical threshold in its development.

In accordance with the blood supply and the oxygen regime of the heart, its bioelectrical activity does not change very sharply in the course of the development of shock. Its changes take the form of a speeding-up of the sinus rhythm, development of high T waves, and a decrease in the S-T interval (A. F. Tur et al., 1960). These changes are completely accounted for by reflex effects as a result of the afferent impulses from the site of injury and hyperkalemia.

The carbohydrate metabolism in the liver changes quite significantly. The glycogen supply to this organ, even at the very beginning of the torpid phase of shock, constitutes only some tenths of a percent as against several percent

under ordinary conditions (S. A. Seleznev, 1964, 1967). The liver loses its ability to utilize glycogen, and as shock becomes more serious resynthesis of carbohydrates from lactic acid is disrupted in the organ. Such changes in the carbohydrate metabolism are assisted to a large extent by hypoxia of the liver (Figure 18). Although the liver in the course of the development of shock switches over to a primarily arterial blood supply (S. A. Seleznev, 1967), when the total volume of perfusion of the organ decreases and there is a limitation of sinusoidal blood flow this is insufficient to ensure a prolonged oxygen regime of the liver.

All of the data presented indicate that there are significant changes in /92
carbohydrate metabolism which takes the form of the development of traumatic shock. These disturbances are caused by disturbances in oxidative phosphorylization, which can be caused by oxygen balance problems.

The changes in carbohydrate metabolism are closely linked to the difficulties with lipid metabolism which are manifested in the torpid phase of shock by acetonemia and acetonuria (I. R. Petrov, 1962).

The development of problems in protein metabolism is indicated by an increase in the content of non-protein nitrogen in the blood primarily due to nitrogen from polypeptides and by a smaller amount of nitrogen in the urine, synthesis of which is disturbed as shock develops (Migone, 1962).

The changes in the composition of serum proteins during traumatic shock are manifested by the decrease in their total level, primarily due to albumins. The latter may have to do both with disturbances in metabolism and with changes in the permeability of the vessels. This assumption is supported by the fact that as shock grows more severe the protein composition of the blood serum levels off somewhat (Figure 19). It should be pointed out that according to our data (S. A. Seleznev, 1964), as shock develops there is an increase in the content of α_2-globulins in that serum which, as we know, have a direct relationship to the vasostimulant properties of the blood.

As a result of these changes in metabolism, which unfortunately have still not been sufficiently investigated, the products of incomplete metabolism accumulate in the organism, and these products possess a high degree of physiological activity. On the other hand, in conjunction with inhibition of the oxidative

processes, there is an accumulation of acid valences and a decrease in the alkaline reserves of the blood. As far back as 1923, Cannon wrote that traumatic shock involves a direct relationship between the decrease in the alkaline reserves of the blood and the accumulation of organic acids.

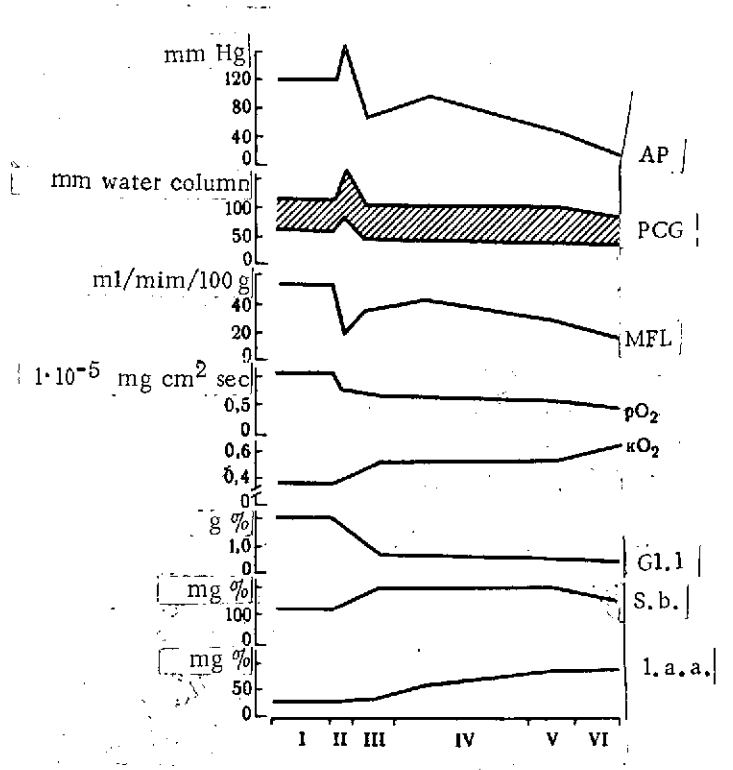

Figure 18. Changes in the Parameters Which Characterize the Functional Status of the Liver During Traumatic Shock. AP, arterial pressure; PCG, porto-caval pressure gradient; MFL, magnitude of flow of venous blood from the liver; pO_2, oxygen tension in the liver tissue; kO_2, coefficient of utilization of oxygen in the aorta-hepatic vein segment; Gl.l., glycogen content in the liver; S.b., sugar content in the arterial blood; l.a.a., lactic acid content in the arterial blood; I, Initial condition; II, Erectile phase; III, Start; IV, Period of stabilization; V, End of torpid phase; VI, Terminal phase.

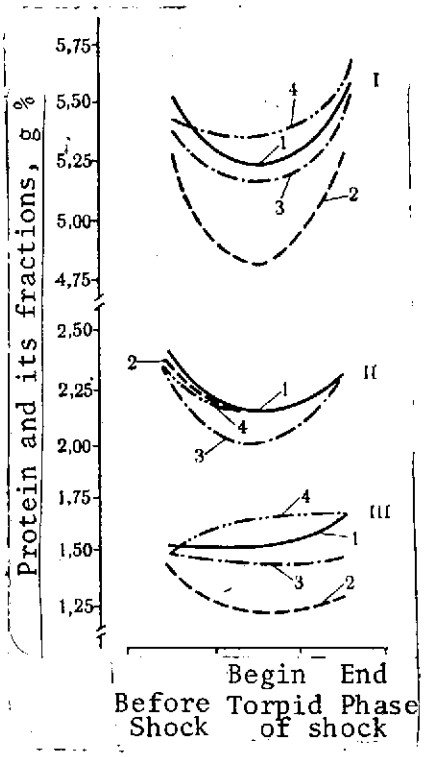

Figure 19. Protein and Protein Fractions of Blood Serum in Various Parts of the Vascular Bed During Shock in the Cat.
I, Total protein; II, Albumins; III, Globulins.
1, Arterial blood; 2, Blood from caudal section of posterior vena cava; 3, Blood from the hepatic section of the posterior vena cava; 4, Blood from the sorbal vein.

Acidosis in traumatic shock may be linked to a disruption of metabolism and /93
the accumulation of carbohydrates. During the initial stages this acidosis is compensated for, but as the shock becomes more serious its decompensation develops rather rapidly.

Significant changes are seen in the ionic composition of the plasma. According to the data of Moon (1942), traumatic shock is marked by the onset of a gradual convergence of the concentrations of ions in the cells and the extracellular fluid, while in the normal situation there is a predominance in the cells of ions of K^+, Mg^{++}, Ca^{++}, HPO_4^-, PO_4^{--}, while the extracellular fluid shows a predominance of Na^+, Cl^-, HCO_3^-. In the opinion of I. R. Petrov (1962), hyperkalemia is characteristic of shock.

Changes in the internal environment of the organism, characterized under ordinary conditions by strict dynamic constancy, cannot but influence the excitability of the nervous and muscular elements and the permeability of cell membranes and vascular walls.

The accumulation of nitrogen products and the changes in the ionic composition of the plasma are promoted by disturbances in kidney function. Oliguria and, in serious cases of shock, anuria are constant in this process. The kidney function disturbances usually correspond to the seriousness of shock. We know that a decrease in arterial pressure to 70-50 mm Hg almost completely stops filtration in the glomerular apparatus of the kidney due to changes in the relationships between the hydrostatic, onco-osmotic, and capsular pressure. However, in traumatic shock, the disturbances of kidney function are not manifested exclusively as the consequence of arterial hypotension: shock is characterized by limitation of cortical circulation due to the increased resistance of the vessels and the shunting of the blood flow through the juxtamedullary pathways. These changes in renal circulation and the associated renal function problems are caused not only by the decrease in cardiac output but also by the increased tone of the vessels of the cortical layer (S. M. Vashentina, N. V. Sinitsyn, 1969).

Regardless of the significant successes achieved in recent years in the study of traumatic shock pathogenesis, many aspects of the mechanism of this reaction still require careful and detailed analysis. In studying the

pathogenesis of traumatic shock, we cannot help but notice the so-called irreversibility of shock. This concept is conditional to a larger degree. Obviously, we must consider two aspects of this problem: irreversibility, which governs the injuries that are incompatible with life and to some degree absolute (at the present time) and irreversibility caused by the faulure of the therapy employed, i.e., related to the effectiveness of therapeutic measures, which is /94 steadily improving.

The concept of irreversibility of shock is closely linked to an evaluation of its seriousness, duration, and accompanying complications. Thus, for example, shock combined with massive blood loss is much more serious than, for example, shock complicated by other pathological processes.

The onset of shock is largely dependent upon the original condition of the organism -- its condition at the moment of action of the harmful mechanical agent. The inability of the regulatory capacities to cope with it, due to previous stress, the decrease in the energy resources, etc., promote the development of irreversible shock.

Long-term circulatory disturbances of the organs, particularly parenchymatous organs, cause them to develop foci of dystrophy and necrosis, which also contribute to the irreversibility of the process. V. A. Negovskiy et al. (1960) found that in the case of prolonged arterial hypotension, death occurs from ischemic injuries to the kidneys, liver and myocardium, while the hypoxic changes in the brain under these conditions may be insignificant.

Peterson and Haugen (1963) link the development of irreversible phenomena during shock with changes in the reticular formation of the brain while Lillehei et al. (1962) connect them with necrotic processes in the submucous layer of the intestine and liver.

I. R. Petrov and G. Sh. Vasadze (1966) are fully justified in stating that only a combination of a number of symptoms, and not any particular one of them, can lead to the development of irreversible phenomena, but they emphasize the exclusive significance of "exhaustion" of the nervous system, suggesting that there is a certain degree of contradiction. Evidently, the principal factor in the development of irreversible shock is a restriction of the accommodative

reactions, especially those which ensure adequate functional status of a given tissue with a supply of oxygen and energy-supplying materials.

Basis of therapy. The complexity of the pathogenesis of traumatic shock, the diversity of the problems with activity of many systems of the organism, differences in concepts regarding the pathogenesis of shock: all combine to produce considerable variation in recommendations on treatment of this process.

The same degree of complexity surrounds the prevention of shock in serious mechanical injuries. When we speak of preventive measures in traumatic shock, we usually have in mind prevention of an increase in the severity of this process, not prevention of the onset of shock as such. Preventive measures must be directed at the maximum possible elimination of afferent impulsation from the zone of injury, restricting the resorption of biologically active and toxic substances, and reducing the intensity of the reactions of nervous, endocrine, and other systems of the organism. All of this is possible to a sufficiently complete degree only when we know the time, zone, dimensions, and nature of the injury, for example in traumatic operations. The prevention of so-called operative shock, being ipso facto a version of traumatic shock, has reached a high level of sophistication thanks to the successes of modern anesthesiology.

Experimental studies make it possible to determine the possible directions of prevention of traumatic shock. Thus, for example, the use of certain combinations of medicinal substances prior to serious mechanical trauma prevents the development of shock. Such complexes include a combined use of truncal narcotics (barbiturates), hormones, and vitamins (V. K. Kulagin, 1956). In later /95
studies, this author showed that prolonged stimulation of the pituitary-adrenal cortex system by the administration of ATCH increases the resistance of animals to shock-inducing traumata.

The experiments of I. N. Yershova (1970) in our laboratory established that the administration of ganglioplegic agents in traumatic shock increases the resistance of animals to additional trauma.

These situations, in which the prevention of shock is essential, are not encountered very frequently. Much more frequently we have to treat developing traumatic shock and, unfortunately, not always during its early periods: in the majority of cases we are faced with the later stages.

The complexity of the pathogenesis of traumatic shock and the participation in its development of various functional systems in the organism govern the principal aspects of the therapy -- its complexity. An important position in the therapy of shock is occupied by the consideration of the phasality of developing shock. Finally, we cannot fail to note the need for a combined use of measures aimed at recovery from shock, with treatment of other consequences of trauma -- fractures, wounds, hemorrhages, and the like.

The treatment of traumatic shock does not eliminate the factors which cause it and therefore is pathogenetic. If we are guided by the concepts regarding the pathogenesis of shock proposed above, it becomes clear that therapeutic measures must include actions to limit the afferent impulsations from the zone of the injury, measures acting upon the dynamics of the phasal processes in the central nervous system, measures to correct the circulation and prevent hypoxia, and means which will make it possible to prevent or eliminate metabolic disturbances and changes in the internal milieu of the organism (G. D. Shushkov, 1967; P. K. D'yachenko, 1968).

The experience of the aid given by the medical service to the wounded during World War II has made possible a comprehensive evaluation of previous recommendations on the treatment of traumatic shock and to expand them in considerable measure. The Medical Service of the Soviet Army did not have access to the most important and systematized data on the treatment of shock, which was embodied in the multiple volume handbook "The Experience of Soviet Medicine in World War II: 1941-1945."

The principal recommendations on shock treatment boil down to the following: a) the need for strict consideration of the degree of severity of the shock; b) the observation of continuity in the treatment of shock in the early stages of medical care with the earliest possible commencement of therapeutic measures; c) the utilization of complex treatment, including neurotropic preparations, blood substitutes, substances to normalize metabolism, immobilization, etc.; d) constant monitoring during treatment on the basis of symptoms characterizing the general condition -- circulation of the blood, respiration and the like; e) timely performance of traumatic operations with the exception of operations with vital indications.

These principles for the treatment of traumatic shock have essentially been retained until the present time, but as we shall see from the following, new and important successes have been achieved in the shock therapy, produced by the discovery of new facts in pathogenesis and the development of a number of effective methods of therapy.

The treatment must be vigorous and as rapid as possible (G. D. Shushkov, 1967). This requirement also governs the methods by which certain medicinal preparations are given, the majority of which are administered directly to the vascular bed.

In the treatment of shock in the erectile phase, when circulatory disturbances have not yet clearly developed, deep hypoxia has not yet arisen, and metabolic disturbances are not yet fully advanced, the measures must consist of preventing their development. In this phase, extensive use is made of substances which limit the afferent impulsation -- various types of novocaine block, analgesics, neuroplegic substances, and narcotics. Analgesics, which inhibit the transmission of impulses, suppress autonomic reactions, and limit sensations of pain, are recommended by many authors during the early periods of shock (G. D. Shushkov, 1967; P. K. D'yachenko, 1968). /96

In the use of neuroplegic substances in shock, the period of definite influence, stimulated to a significant degree by the work of Laborit, has changed to a moderate and even considerable degree, having to do with their pronounced hypotensive effects (G. D. Shushkov, 1967). Anesthesia, particularly that induced by nitrous oxide, is recommended for the early stages of shock. The analgesic effect of nitrous oxide, its blockage of the transmission of impulses in the ascending branch of the brain stem, and the favorable influence of blood circulation all serve as the basis for this recommendation.

An important factor which limits the impulsation from the site of the injury is the resting of the injured area (immobilization, bandaging, and the like).

In the erectile phase of shock, the use of saline solutions is recommended, which contain neurotropic and energetic substances (Popov's fluid, Petrov's fluid, Filatov's fluid, and the like).

The treatment of traumatic shock in its torpid phase is much more complicated, especially in the case of severe shock. An important position among the therapeutic measures in this case is once again occupied by the various measures aimed at limiting the afferent impulsation, which during this period of shock occurs not only from the zone of the injury, but also from the organs which have their functions disturbed. Among the measures to limit the input of afferent impulses are immobilization, novocaine block, and ganglia-blocking substances. In this connection, since the latter possess significant hypotensive effects, it is recommended that so-called gangliar block be used without hypotonia, ensuring prevention of hypotension by the administration of vasopressor substances (P. K. D'yachenko, 1968; G. D. Shushkov, 1967). The theoretical fundamentals and methods for the execution of a gangliar block cannot be considered to have been finally worked out. Thus, for example, I. N. Yershova (1970) has shown conclusively that it is better to produce a ganglia block not only by administration of vasopressor substances but also with arterial transfusions.

Significant disturbances of circulation, tissue respiration and metabolism, which occur during the torpid phase of shock, require different measures, aimed at their correction. The success of therapy aimed at elimination of circulatory disturbances is usually determined by the level of arterial pressure, and only sometimes central venous pressure; unfortunately these parameters insufficiently reflect the state of perfusion of the tissues with blood. In order to evaluate total tissue perfusion, it is necessary to determine the parameters of the volume velocity of blood flow and, in particular, the magnitude of cardiac output (minute volume of circulation). A study of the condition of the tissue perfusion must be the basic criterion for successful transfusion therapy. To correct circulatory problems, transfusions of either blood or blood substitutes are carried out. In acute shock, the most effective method is intra-arterial transfusion. Their high efficiency has been connected by certain researchers with the stimulation of vascular receptors (G. D. Shushkov, 1967), while others have /97 linked it to an increase in the capillary blood flow and the expulsion of a portion of the deposit (Figure 20).

In this connection, since shock primarily involves deposition and aggregation of the formed elements, it appears very promising to use the all-molecular

colloid plasma substitutes (dextrans, polyvinyls), which possess a disaggregative effect and reduce viscosity of the blood with low shift potentials (S. A. Seleznev, 1964; O. P. Khrabrova, 1967; D. Ye. Van'kov, S. A. Seleznev, O. P. Khrabrova, 1970).

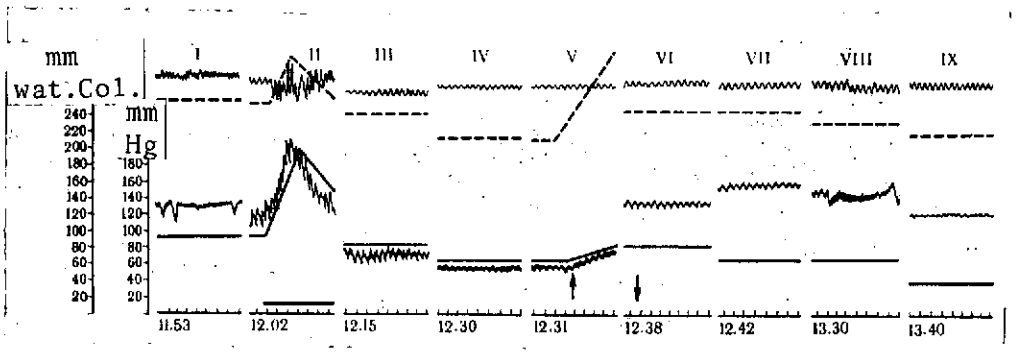

Figure 20. Development of Experimental Traumatic Shock, Treated by Intra-arterial Blood Inhibition.
I, Original data; II, Erectile phase; III, IV, Torpid phase prior to treatment; V, In the course of inhibition of blood flow; VI-IX, Following treatment. From top to bottom (according to original data): respiration; pressure in the portal veins; arterial pressure; pressure in the vena cava; time mark.

In recent years, auxiliary perfusion with artificial circulation apparatus has come into use in recent years for elimination of circulatory disturbances during shock, primarily under experimental conditions. In all likelihood these measures will be quite effective inasmuch as they can considerably improve the tissue blood flow, but there is still a great deal which is not clear regarding this problem, and it is particularly necessary to synchronize the pump action with the contractions of the heart, which is a very difficult thing to do.

Checking the adequacy of blood transfusions on plasma substitutes is quite complicated; it is necessary to use a number of parameters for this purpose, especially the total volume of circulating blood and the minute volume of circulation. Measurement of the central venous pressure, which is most frequently employed in the clinic, provides only a fairly relative type of information with respect to the venous return to the heart.

The use of vasopressors in traumatic shock, a measure aimed at increasing arterial pressure, has passed through a period of rapid development and subsequent decline. These substances, primarily pressor amines, are known to increase the tone of the resistive vessels, something which by itself will not improve the tissue blood flow except in a certain area. Administration of one of the most popular vasopressors -- noradrenaline -- at the initial stage of the torpid phase increases the minute volume of blood circulation somewhat due to expulsion of a portion of the deposited blood, and improves blood supply to the brain and /98 myocardium. However, the use of noradrenaline during later periods of shock may even restrict the central blood circulation typical of it. Under these conditions, the use of noradreanaline is advisable only as an "emergency" measure.

The restoration of circulation during traumatic shock is one of the principal ways of eliminating hypoxia. Many authors, primarily non-Russian, feel that in order to restore tissue blood circulation it is necessary to use not vasopressors which have a vasoconstrictive effect, but vasodilators of the adreno-blocking type -- dibenzamine and dibenzyline (Nickerson, 1962; Lillerei et al., 1962).

The use of ganglia-blocking substances in conjunction with blood transfusion to prevent the onset of hypotension, promotes an increase in heart efficiency and improves blood flow in the terminal portions of the vascular bed -- the microcirculation (I. N. Yershova, 1970).

The use of saline plasma substitute solutions, although it does temporarily restore the blood flow, does not produce a prolonged effect. These solutions, in the case of serious disturbances of capillary blood flow and changes in the relationships between the onco-osmotic and hydrostatic forces, characteristic of shock, leave the vascular bed comparatively rapidly.

Some researchers find saline solutions to be very effective when administered into the arterial bed, and link this efficiency with a stimulation of the arterial receptors. This type of opinion, based on data from experiments using hypertonic solutions, must be viewed critically.

A significant influence on blood flow during traumatic shock is exerted by hormones, ACTH, and cortisone, which are given to normalize the metabolic processes. As we mentioned earlier, in the course of development of shock there is initially a relative (and later absolute) adrenal insufficiency. In the light of these data, the use of ACTH seems to be more advisable during the early stages of shock or during its prevention.

Glucocorticoids, given during the torpid phase, have a multiform effect. They change the reaction of the vessels to the vasostimulants, and in particular they intensify the effects of vasopressors. In addition, they reduce vascular permeability (P. D. Gorizontov, T. N. Protasova, 1966). When it is most important, their effect is linked to the influence upon the metabolid processes, especially carbohydrate metabolism.

Many authors have noted the favorable effect of cortisone and hydrocortisone on the course of experimental shock (I. R. Petrov, 1962; V. K. Kulagin, 1965; G. D. Shushkov, 1967). The mechanism of this positive effect is still insufficiently clear.

The restoration of oxygen balance under shock conditions is provided not only by the restoration of circulation but also by the use of oxygen therapy (G. D. Shushkov, 1967). In recent years, oxygen-barotherapy has also been recommended (G. Sh. Vasadze et al., 1968).

In order to improve the metabolic processes, the majority of investigators have proposed the use of vitamin preparations in the treatment of shock. The following are particularly recommended: ascorbic acid, involved in the tissue respiration process; thiamine, which is a co-ferment of pyroracemic acid oxidase, participating in decarboxylization of ketoacids and thereby promoting the restoration of carbohydrate metabolism; pyridoxin, which goes to make up the enzymes of reamination and decarboxylization. G. D. Shushkov (1967) suggests that it is valuable to include among the antishock substances vitamin B_{15} /99 (pangamic acid), which increases the utilization of oxygen and increases the level of creatinine in the heart muscle.

In conjunction with the increased resorption of the proteinogenic amines and especially histamines from the injured tissues, an important role in the treatment of traumatic shock may be played by the use of antihistamines.

An important place in the treatment of shock is occupied by the correction of acid-alkaline balance. Acidosis is typical of traumatic shock. Its development is governed both by metabolic disturbances and by the accumulation of carbohydrates. The development of acidosis is also promoted by the disruption of the excretory processes. In order to reduce acidosis, it is recommended that sodium bicarbonate be given (G. D. Shushkov, 1967); however, some feel that it is better to use sodium lactate or tris-buffer -- TNAM (P. K. D'yachenko, 1968).

Hence, the therapy of traumatic shock is complicated and still largely incomplete. It is very difficult to evaluate recommendations on surgery under shock conditions, but such operations are very frequently necessary in injuries so serious as to cause shock. The operation itself is an additional trauma and even under conditions of modern anesthesiological care the shock is frequently intensified. In these cases there are no simple answers: it is necessary to take into account the danger of the injury requiring surgery, and the seriousness of the traumatic shock, as well as the period of its development and the possibility of anesthesiological care, together with a number of other factors.

The literature contains a number of suggestions for methods of treatment of traumatic shock (G. D. Shushkov, 1967; P. K. D'yachenko, 1958; A. N. Berkutov, 1968). The majority of these systems, while they have some degree of similarity, do differ in important respects, but this is only a further indication that attempts to find a more rational therapy for traumatic shock must continue.

Pain From Injury

In recent years it has been shown very clearly that massive injury to some tissues, their suppression in the initial stage of development of disease, is characterized by a number of reactions which theoretically are no different from traumatic shock (V. K. Kulagin, 1965; A. A. Zor'kin et al., 1968). This is understandable, since this type of injury involves intensive afferent impulsation caused by irritation of nerve elements and injury to vessels as well as injury to the intactness of tissue elements, i.e., all the components which in only a few other quantitative respects can be found in traumatic shock (see Figure 10). Some authors even write directly about shock in the prolonged compression of tissues (A. A. Zor'kin et al., 1968).

Pathogenesis. When experimental compressive disease is produced by compression, there is motor restlessness, an increased reaction to painful and tactile stimuli, cries, urination, defecation, increased arterial pressure, dyspnoea (A. A. Zor'kin et al., 1968), i.e., the entire complex of systems characteristic of the erectile phase of traumatic shock. During this phase there is a greater degree of vascular pressor reactions and symptoms of increased activity of the pituitary-adrenal system.

The erectile phase of shock during compression of soft tissues is only slightly more prolonged in time in comparison with shock caused by brief action of mechanical stimulation of an excessive force. In the erectile phase of shock /100
from compression of soft tissues, there are also characteristic changes in metabolism associated with traumatic shock -- increased activity of oxidative processes, intensification of glycogenolysis, and so forth.

With prolonged compression, after a short period of time one can see the onset of the following phase, which is no different in its characteristics from the torpid phase of ordinary traumatic shock and is characterized by the development of inhibition in the central nervous system, endocrine disturbances, circulatory problems, hypoxia, changes in metabolism and externally by prolonged inhibition, torpidity, arterial hypotension, rapid pulse, and so forth.

The simularity between the typical traumatic shock and shock involving extensive injury to soft tissues is very great. It is no accident that in studying the general features of traumatic shock, the experimental model, using practically the same guidelines, is used for traumatic shock according to Cannon and shock from compression of soft tissues.

After several hours of compression, particularly following decompression in the course of disease caused by extensive compression of soft tissues, the characteristic features develop.

The distinctive nature of the pathological process is quite complex and was studied from a number of viewpoints during World War II. Initially this reaction was called traumatic edema, emphasizing the fact that after a certain period of time has elapsed following trauma, extensive edema develops in the region of the injury. Later it came to be called the crushing syndrome -- or, from the name

of the author who first described it in detail -- the Bywaters syndrome. In the USSR this disease was called during the early years the crush syndrome, then traumatic toxemia and finally the prolonged crushing syndrome -- PCS (M. I. Kuzin, 1959). The latter name has acquired widest usage.

As we have already pointed out above, the syndrome consists of a complex of symptoms which constitute the external manifestations of a given disease, a given pathological process, and not its essence; we consider it therefore to be advantageous in describing the reactions of the organism to extensive crushing of soft tissues, to call this pathological process the crushing disease. Many changes in the vital activity of the organism, characteristic of crushing disease, are observed in various types of extensive muscular necrosis and during muscle breakdown.

M. I. Kuzin (1959), describing the syndrome of prolonged crushing in victims of landslides during earthquakes, views it as a phasal process, dependent upon the severity and extent of the injury and the accompanying phenomena. He criticizes the opinion of those researchers who view the early stages of the crushing disease as traumatic shock, feeling that in half the cases, when soft tissues are crushed, there is a so-called "shock-type phenomenon." M. I. Kuzin analyzes its later stages of the process, which can be observed after the victims have been removed from the ruins, in much greater detail than the early stages. In other words, he places considerably more importance on the period of the syndrome of prolonged crushing which some authors call "freeing disease."

During the very first few moments after decompression, it is sometimes possible to observe a combination of changes in the function of the organism which resembles the torpid phase of traumatic shock, but very rapidly the disease becomes such that it takes on very characteristic features peculiar to it alone, caused by the development of edema in the zone of injury, and toxemia.

M. I. Kuzin distinguishes three periods in the syndrome of prolonged compression: early -- first -- 2-3 days following liberation, intermediate -- 3-4 days, and late, lasting from 8-12 days to 1-2 months. He lists the distinguishing features of the prolonged crushing syndrome as follows: thickening of the blood, toxemia, oliguria, and characteristic changes in the urine (appearance of myoglobin, blood, and cylinders in the urine). /101

Following decompression, one usually sees brief excitation, followed by a rapid onset of acute inhibition. All of this is very reminiscent of the reaction of the organism to the repeated trauma against the background of traumatic shock. Essentially this is as should be expected, since in the course of decompression the elements of the nervous system in the zone of the injury are re-stimulated, with stimulation of the endocrine apparatus and an important redistribution of the circulating blood.

In experiments on dogs, rats and other animals, after the compressive vices were removed, there was a gradual increase in the size of the extremity as to its volume, the development of hemorrhage, and development of edema distal to the point of compression. The edema reaches levels close to the maximum after only 1-1.5 hours. After 2-3 days, necrosis of the skin can be seen in the zone of the injury; the necrotic muscles begin to slacken, and this is frequently combined with purulent infection. The point of injury recovers with a gradual slackening of the necrotizing tissues, granulations, and scarring. Practically speaking, this same sequence of phenomena is described in human beings rescued from beneath landslides.

Simultaneously with a complex of local changes are other symptoms characteristic of the crushing disease, particularly disturbances in urination, which decreases sharply 1-2 hours after decompression (Figure 21). Sometimes, where the course of the disease is favorable, it is restored gradually but slowly (M. I. Kuzin, 1959).

Following decompression, the urine gradually becomes red and later dark brown due to kidney excretion of myoglobin. It contains a great many proteins as well as hyalin and blood cylinders. During this period there is a considerable increase in the non-protein nitrogen level in the blood and in ureic nitrogen, the amount increasing by the 2nd to 3rd day of the disease by a factor of 1.5 to 2 and sometimes more.

The ionic composition of the plasma changes as well; there is a marked increase in the content of potassium ions and phosphates and a decrease in the sodium and chlorine content. All of this inevitably has an influence on the excitability of the nerve and muscle elements and the permeability of the /102
vascular and tissue membranes (Ye. B. Zakrzhevskiy, A. A. Dyskin, 1964).

Hyperkalemia has been used to describe the changes occurring in the ECG and the disturbances in the heart rhythm.

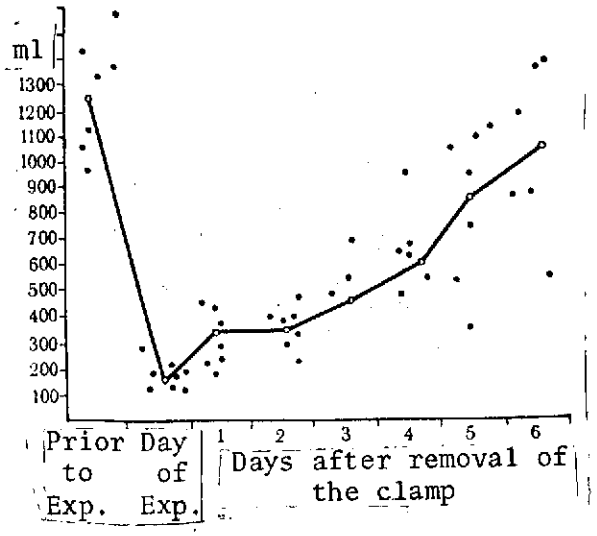

Figure 21. Daily Diuresis in the Dog at Various Periods Following Crushing of Soft Tissues (After M. I. Kuzin, 1959). The points represent data from individual experiments.

Autopsies performed on animals sacrificed after their muscle tissues had been compressed revealed necrotic changes in some muscle fibers in the area of the injury of the Tsenkerov necrosis type, edema and homogenization of other fibers, and leukocytic infiltration of the injured tissues. The internal organs are usually plethoric, while some of them show very typical changes, for example hemorrhages in the intestines and plethora of the medullary and ischemia of the cortical layers of the kidneys, dilation of Bowman's capsule, cloudy swelling and granular degeneration of the epithelium of the convoluted tubules, with protein masses accumulating inside them. Degenerative changes are most pronounced in the distal portions of the convoluted tubules and ascending branch of the Henle's loop (Ye. B. Zakrzhevskiy, A. A. Dyskin, 1964). The changes in the kidneys, appearing as dystrophic changes typical of the 2nd or 3rd day of the disease, are widespread. Later, on the 3rd to 5th day, one begins to see signs of regeneration of the injured kidney tissue (epithelium) and leukocytic infiltration (M. I. Kuzin, 1959). It is necessary that we consider typical of crushing disease the development of cylinders in the convoluted tubules, especially cylinders from the myoglobin.

One of the basic pathogenetic factors in the later stages of the crushing disease must unquestionably be intoxication and plasma loss. Myoglobin, creatine and intracellular ions enter the blood from the injured tissues, primarily the muscles (Bywaters). Cannon and Bayliss found that the liberation

of arteries ligated previously (before the mechanical trauma) sharply increases the severity of shock. However, P. N. Veselkin et al. (1936) observed no phenomena typical of traumatic shock when he gave animals extracts taken from muscle. Of course, we must take into account that crushing disease involves resorption of products not from ordinary but injured tissues, particularly the products of the breakdown of necrotizing muscle. Some investigators feel that the products of injured skin are particularly toxic. These products are resorbed primarily from those areas bounded by the zone of injury, where the blood supply remains satisfactory, while some come from the injured zone. Both Soviet and foreign authors, in experiments involving the use of isotope methods, have shown that there is a real possibility of this kind of resorption from the injured tissues.

M. I. Kuzin (1959) observed that, about 1 hour after decompression, substances appear in the edematous fluid from injured tissues with a depressor effect that cause pronounced arterial hypotension. The edematous fluid has some vasodilatory properties with respect to the vessels of the isolated rabbit ear. However, transfusion of large amounts of blood from animals subjected to crushing of the soft tissues to intact animals failed to produce any phenomena similar to the crushing disease.

There is reason to believe that significantly injured tissues may liberate bradykinin which has pronounced vasodilatory properties, and perhaps other hypotensive kinins as well. As we have already pointed out, an important place in the pathogenesis of the crushing disease is occupied by plasma loss. The amount of edematous fluid in the experiments conducted on animals reaches 4-5% of body weight. It is specifically with the loss of fluid into the injured tissues, and most of this fluid is of plasmatic origin, that the decrease in the volume of the circulating blood and its thickening are related. The decrease in the /103
volume of the circulating blood causes changes in the productivity of the heart, and thickening of the blood affects its rheological properties, which altogether cause the characteristic circulatory disturbances. These problems are very reminiscent of the circulatory difficulties involved in traumatic shock in its later stages, and are expressed (in addition to the above-described arterial hypotension) by a redistribution of the blood flow. Resorption of the vasostimulant products from the zone of injury sharply intensifies the circulatory problems.

Hypoxia phenomena develop due to the circulatory disturbances and changes in tissue metabolism. Development of this phenomenon is governed to a large measure by the changes in external respiration, which develop not only as a reaction to hypoxia, but also as the result of disturbances of the activity of the brain centers in conjunction with nociceptive stimulation and intoxication.

Disturbances of metabolism during the decompression period take the form of inhibition of oxidative processes and intensification of the glycolytic processes in the tissues. The consumption of oxygen by the tissues of the brain, heart, and liver decreases (A. A. Zor'kin et al., 1968). It has been suggested that stimulation of metabolism during the early periods of the crushing disease is the result of hormonal effects. At later stages of the disease, some of the corticoids are bound by the plasmatic proteins, becoming inactive, which promotes inhibition of metabolism. However, the viewpoint regarding the great significance of corticoid feedback with proteins in changes of hormone activity has not been shared by many authors.

Toxemia in crushing disease has to do with the intake of the toxic products of disturbed metabolism and a change in kidney function. As we pointed out earlier, the mechanism of the disruption of kidney function is still not completely clear. Initially, considerable importance was laid upon blockage of the channels by myoglobin, which is excreted primarily by the kidneys. However, the lack of a definite correlation between the severity of the disease and the number of blocked channels makes such an explanation difficult. In addition, it was found that the unblocked channels also lose their ability to reabsorb.

The filtration capacity of the glomerular apparatus of the kidneys is also disturbed. Trueta et al. (1947) and other researchers have suggested that this may be explained by a spasm of the vessels in the cortical layer, leading to its ischemia and a decrease in the level of filtration pressure. However, degenerative changes in the distal portion of the tubules and the Henle's loops, in the opinion of Trueta et al., are linked to hypoxia of the renal tissue. Denervation of the kidneys in their experiments decreased the spasms of the vessels of the cortical layer, typical of crushing disease. Experiments with kinoangiography, performed by Trueta, showed that during the compression period, linear velocity of the renal blood circulation decreases, while after decompression it rises

somewhat; however, this increase in linear velocity in no way indicates an improvement of perfusion of the renal tissue, inasmuch as it is accompanied by a passage of the blood through shunting of vessels, and under such conditions circulation in the terminal vessels of the cortical layer practically ceases.

In the experiments of M. I. Kuzin (1959), involving perfusion of the isolated kidney with blood serum taken from animals subjected to crushing of the extremities, it was found that the renal vessels respond to substances containing it by spasm. Thus, the spasm of the vessels of the cortical layer is caused by intensive afferent impulsation on the one hand and the effect of vasoactive substances on the other. It is combined with shunting of the blood flow through juxtamedullary vessels.

The dystrophic processes in the renal apparatus too, in all likelihood, /104
cannot be explained simply: initially their development is caused by hypoxia of the renal tissue, while later this is combined with the irritating and damaging effects of the products of autolysis and the disruption of tissue metabolism.

Basic principles of therapy. The basic principles of treatment of crushing disease are largely similar to the principles previously considered for treating traumatic shock: this therapy must be complex and strictly dependent upon the severity of the process and the period of its development. In the initial period of crushing disease, it is necessary to take measures to limit the afferent impulsation from the point of injury, restore the disturbed circulation, prevent hypoxia, and correct metabolic disturbances. Limitation of afferent impulsations is achieved by immobilizing the injured extremities and applying measures to prevent edema.

To treat disturbances of blood circulation (and in crushing disease, in contrast to traumatic shock, these are combined with a thickening of the blood) it is advantageous to employ plasma-substitute solutions. Preference must be given to the low-molecular colloid plasma substitutes of the low-molecular type such as dextran or low-molecular polyvinyl and gelatinol, which, in addition to everything else, promote disaggregation of the formed elements. Administration of saline solutions, in the opinion of some authors (Laborit, 1952), also has a very favorable effect upon blood circulation and if we take into account the

fact that these solutions promote stimulation of diuresis, the advisability of using them becomes still more evident.

During the early stages of crushing disease and as soon as possible after decompression, it is necessary to adopt measures to reduce resorption from the injured tissues. For this purpose, local hypothermia and mild degrees of compression are applied (M. I. Kuzin, 1959).

A very important aspect is the restoration of kidney function and prevention of renal insufficiency. For this purpose, paranephral blockades are applied, and glucose and saline solutions administered. Some authors recommend, for the purpose of administration of toxic products, that peritoneal dialysis be employed. In recent years many have recommended the use of artificial kidneys (Ye. B. Zakrzhevskiy, A. A. Dyskin, 1964).

One very important thing in crushing disease is direct action to restore the disturbed metabolism and the acid-alkaline balance, for which hormonal preparations, vitamins and alkaline solutions are employed, as described in conjunction with the treatment of traumatic shock. All of these therapeutic measures must be viewed as a constant monitoring not only of the most important functions of the organism but also of those particularly important to compression disease and the chemical composition and physical-chemical properties of the blood.

To conclude this description of the pathogenesis of traumatic shock and crushing disease and the basic principles of its treatment, we cannot fail to note that it is impossible to review all the literature devoted to this problem. Our aim was to give as objective as possible a picture of the most important data and the most widespread views on these processes. It is possible that, as in any field of knowledge, these views will not be permanent: new facts will come to light, and the extensive exchange of opinions between scientists will expand. At the same time, we must emphasize that in recent years a great many important data have been gathered on the pathogenesis of the reactions of the organism arising in serious mechanical injuries. These data have stimulated the search /105 for and analysis of new methods of shock diagnosis, prognosis and therapy, many of which require still more careful examination in the clinic.

REFERENCES

Aktual'nyye Voprosy Patofiziologii Travmy. Sbornik Rabot Kafedry Patofiziologii [Current Problems of the Pathophysiology of Trauma. A Handbook of the Work of the Department of Pathological Physiology], Kishinev, 1969.

Akhunbayev, I. K. and G. L. Frenkel', *Ocherki po Shoku i Kollapsu* [Outlines of Shock and Collapse], Frunze, 1967.

Algoewer, M., "Traumatic Shock," in the book: *Ergebnisse der Chirurgie und Orthopaedie* [Results of Surgery and Orthopedics], Berlin, Vol. 41, p. 1, 1958.

Asratyan, E. A., *Ocherki po Etiologii, Patologii i Terapii Travmaticheskogo Shoka* [Outlines of the Etiology, Pathology and Therapy of Traumatic Shock], Moscow, 1945.

Berkutov, A. N., "Traumatic Shock in Man," in the book: *Travmaticheskiy Shok u Cheloveka* [Traumatic Shock in Man], Leningrad, p. 16, 1968.

Burdenko, N. N., *K Ucheniyu o Shoke. Sbornik Sochineniy* [The Science of Shock. A Collection of Articles], Moscow, Vol. 3, p. 86, 1951.

Burton, A. C., *Physiology and Biophysics of the Circulation*, Chicago, 1966.

Cannon, W. B., *Traumatic Shock*, New York, 1923.

Davydovskiy, I. V., *Ognestrel'naya Rana Cheloveka* [Wounds Caused in Man by Fire], Moscow, Vol. 2, 1954.

D'yachenko, P. K., *Khirurgicheskiy Shok* [Surgical Shock], Leningrad, 1968.

Fedorov, I. I. and D. M. Sherman, "Some Disputed Problems in the Pathogenesis of Traumatic Shock," *Nov. Khir. Arkh.*, Vol. 10, No. 3, 1961.

Fine, J., "Traumatic Shock," *Surg. Clin. N. Amer.*, No. 43, p. 597, 1963.

Frank, H. A., "Present-Day Concepts of Shock," *New Engl. J. Med.*, No. 249, p. 445, 1953.

Gordiyenko, A. N., *Osnovnoy Mekhanizm Razvitiya Travmaticheskogo Shoka* [The Fundamental Mechanism of the Development of Traumatic Shock], Kiev, 1956.

Gorizontov, P. D. and T. N. Protasova, "Role of the Pituitary-Adrenal Cortex System in the Reactivity of the Organism in a State of Stress and in the Pathogenesis of Certain Non-Endocrine Diseases," in the book: *Mnogotomnoye Rukovodstvo po Patologicheskoy Fiziologii* [Multivolume Handbook on Pathological Physiology], Moscow, Vol. 1, p. 115, 1966

Hardaway, R. W. and D. G. Johnson, "A New Theory of Shock," *Milit. Med.*, No. 128, p. 198, 1963.

Hershey, S. G, "Current Theories of Shock," *Anesthesiology*, No. 21, p. 303, 1960.

Khrabrova, O. P., "Circulation of the Blood During Traumatic Shock," Doctoral Dissertation, Leningrad, 1969.

Kulagin, V. K., *O Ranney Profilaktike Travmaticheskogo Shoka i Izmeneniyakh Reflektornoy Deyatel'nosti, Vyzvannykh Mekhanicheskoy Travmoy* [Early Prevention of Traumatic Shock and Changes in the Reflex Activity Caused by Mechanical Trauma], Leningrad, 1956.

Kulagin, V. K., *Rol' Kory Nadpochechnikov v Patogeneze Travmy i Shoka* [The Role of the Adrenal Cortex in the Pathogenesis of Trauma and Shock], Leningrad, 1965.

Kuzin, M. I., *Klinika, Patogenez i Lecheniye Sindroma Dlitel'nogo Razdavlivaniya* [Clinical Aspects, Pathogenesis and Treatment of the Prolonged Compression Syndrome], Moscow, 1959.

Laborit, H., *Réaction Organique à l'agression et choc.* [Organic Reaction to Agression and Shock], Paris, 1955.
Laborit, H., *Les Regulations Metaboliques* [Metabolic Regulation], Paris, 1965.
Levtov, V. A., *Khimicheskaya Regulyatsiya Mestnogo Krovoobrashcheniya* [Chemical Regulation of Local Blood Circulation], Leningrad, 1967.
Moon, V. H., *Shock: Its Dynamics, Occurrence and Management,* Philadelphia, 1942.
Osnovy Reanimatologii [Fundamentals of Reanimatology], edited by V. A. Negovskiy, Moscow, 1966.
Petrov, I. R., *Shok i Kollaps* [Shock and Collapse], Leningrad, 1947.
Petrov, I. R. and G. Sh. Vasadze, *Neobratimyye Izmeneniya Pri Shoke i Krovopotere* [Irreversible Changes During Shock and Hemorrhage], Leningrad, 1966.
Popov, V. I., *Etiologiya i Patogenez Travmaticheskogo Shoka. Opyt Sovetskoy Meditsiny v Velikoy Otechestvennoy Voyne 1941-1945 gg.* [Etiology and Pathogenesis of Traumatic Shock. Experience of Soviet Medicine in World War II, 1941-1945], Moscow, Vol. 3, p. 342, 1953.
Seleznev, S. A., "The Liver in Traumatic Shock," Doctoral Dissertation, Leningrad, 1964.
Seleznev, S. A., "Reactions of the Liver to Serious Damage to the Organism," *Epatologia,* Vol. 13, p. 3, 1967.
Seleznev, S. A., "The Mechanism of Disturbances to Blood Circulation in Traumatic Shock," *Pat. Fiziol.,* Vol. 6, No. 3, 1968.
Seleznev, S. A. and O. P. Khrabrova, "The Basic Features of Disturbances of Blood Circulation in Traumatic Shock," *Vestnik AMN SSSR,* Vol. 7, p. 43, 1967.
Seleznev, S. A. and O. P. Khrabrova, "The Most Important Features of the Microcirculation in Traumatic Shock," *Kardiologiya,* No. 9, p. 28, 1969.
Shock and Hypotension, Edited by L. C. Mills and T. H. Moyer, New York, 1965.
Shock, Pathogenesis and Therapy, Edited by K. D. Bock, New York, 1962.
Shock, Edited by S. G. Hershey, Boston, 1964.
Shok. Trudy Konferentsii po Probleme Shoka [Shock. Transactions of a Conference on the Problem of Shock], edited by A. A. Bogomol'ts, Kiev, 1938.
Shok i Terminal'nyye Sostoyaniya. Trudy Nauchnoy Sessii, Posvyashchennoy Pamyati I. I. Dzhanelidze [Shock and Terminal States. Transactions of a Scientific Session devoted to the Memory of I. I. Dzhanelidze], Edited by L. I. Garvin, Leningrad, 1960.
Shushkov, G. D., *Travmaticheskiy Shok* [Traumatic Shock], Leningrad, 1967.
Symposium of Shock, *Am. J. Surg.,* No. 110, p. 293, 1965.
Thal, A. P. and J. M. Kinney, "On the Definition and Classification of Shock," *Progr. Cardiovasc. Dis.,* No. 9, p. 527, 1967.
Travmaticheskiy Shok [Traumatic Shock], Edited by I. R. Petrov, Moscow, 1962.
Travmaticheskiy Shok. Materialy Nauchnoy Konferentsii Leningradsk. Nauchno-Issled. in-ta Skoroy Pomoshchi [Traumatic Shock. Materials of a Scientific Conference of the Leningrad Scientific Research Institute of First Aid], Edited by G. D. Shushkov, Leningrad, 1970.
Travmaticheskiy Shok, Ostryy Zhivot, Infarkt Miokarda. Materialy Yubileynoy Sessii Leningradsk. Nauchno-Issled. in-ta Skoroy Pomoshchi [Traumatic Shock, Acute Stomach, Myocardial Infarct. Materials of the Jubilee Session of the Leningrad Scientific Research Institute of First Aid], Edited by G. D. Shushkov, Leningrad, 1967.

Travmaticheskiy Shok u Cheloveka. Materialy Konferentsii [Traumatic Shock in Man. Materials of a Conference], Leningrad, 1968.
Trueta, J., *Studies on the Renal Circulation*, Oxford, 1947.
Vashetina, S. M. and N. V. Sinitsyn, "Renal Circulation in Experimental Traumatic Shock," *Pat. Fiziol.*, Vol. 6, p. 35, 1969.
Voprosy Neyro-Gumoral'nykh Narusheniy Pri Travme. Sbornik Rabot Kafedry Patofiziologii [Problems of Neuro-Humoral Disturbances in Trauma. A Collection of Works of the Department of Pathological Physiology], Edited by A. A. Zor'kin, Kishinev, 1966.
Wiggers, C. J. *Physiology of Shock*, New York, 1950.
Zakrzhevskiy, Ye. B. and A. A. Dyskin, "The Crushing Syndrome (Survey of the Literature)," *Sov. Med.*, Vol. 8, p. 88, 1964.
Zavetnaya, G. L., "Some Characteristics of the Reflex Regulation of Circulation of the Blood in Traumatic Shock," Candidate's Dissertation, Leningrad, 1968.
Zetkin, M., *Die Chirurgie des Traumas* [The Surgery of Trauma], Berlin, 1955.
Zweifach, B. W., *Functional Behavior of the Microcirculation*, Springfield, 1961.

Translated for the National Aeronautics and Space Administration under contract No. NASw-2485 by Techtran Corporation, P. O. Box 729, Glen Burnie, Maryland, 21061. Translator: William J. Grimes.